Annual Review: Supplement

Activities of the BIPM Departments

1 January 2021 – 31 December 2021

Bureau
International des
Poids et
Mesures

Contents

This supplement reports activities on the projects detailed under the Work Programme (2020 – 2023).

The report is published annually and covers the calendar year.

Key achievements *(1 January 2021 – 31 December 2021)*

The Work Programme for 2020 – 2023 is described in terms of 9 major activities, including 68 projects and 100 tasks for the BIPM. Some of the key activities during the reporting period are highlighted below:

LABORATORY WORK CARRIED OUT BY THE BIPM

- **Physical Metrology**
  - Following the first key comparison of kg realizations, organized by the BIPM, the first CCM consensus value for the kg was determined by the BIPM.
  - A graphene sample, has shown good quantization at low magnetic field and high temperature. This is a first step in the realization of a new compact graphene-based QHR system.
  - For the first time a relative difference of a few parts in 10^8 could be achieved in a pilot study of sinusoidal ac voltages below 1 kHz at 1 V, in preparation of a future key comparison.
- **Time Metrology**
  - Development of a test API based on the UTC data base https://webtai.bipm.org/api/v0.1/ giving access to machine readable data regarding UTC and rapid UTC.
  - Development of the capacity to compare clocks by the Integer PPP technique, also used to validate other very precise time and frequency methods https://www.bipm.org/en/-/2020-optical-clocks
  - Development and use a new estimation technique for the reference frequency values of PSFS and their correlation with the Joint CC CCTF WG on frequency standards.
- **Chemical Metrology**
  - 1st CO_2 isotope ratio comparison in support of atmospheric monitoring and scale realization ($\delta^{13}C$ and $\delta^{18}O$) launched, CCQM-P204.
  - On-line knowledge transfer programmes launched in Metrology for Food Safety and Clean Air, with over 110 participants.
  - 1st comparison on SARS-CoV-2 antibody quantification completed and published, CCQM-P216.
- **Ionizing Radiation Metrology**
  - Full range of the BIPM services made available for the NMIs in the high-energy photon facility (DOSEO), including key comparisons and calibrations.
  - Commissioning and validation of the new medium-energy x-ray generator at the BIPM.
  - Successful first remote comparison with SIRTI.
  - Close completion of the pilot study with ^{60}Co to valid the extended SIR (ESIR) system.

INTERNATIONAL LIAISON

- Signing of the BIPM-CTBTO Practical Arrangement in June 2021.
- Signing of the BIPM-CODATA MoU in October 2021.
- Participation as a panelist in the OECD High-Level virtual tour de table: *"Rethinking and modernizing international rulemaking to design better policies for the 21st century"*.

COORDINATION

- GULFMET became a full member of the JCRB.
- Revised CIPM MRA policy and guideline documents have been published.
- First CD of VIM4 was sent to NMI Directors and JCGM MOs for consultation.

CAPACITY BUILDING AND KNOWLEDGE TRANSFER

- Launch of the BIPM's e-learning platform with four e-learning courses related to scientific metrology activities, including the mechanisms of the CIPM MRA.
- Launch of laboratory based on-line knowledge transfer programme on Metrology for Food Safety and Clean Air.

COMMUNICATION AND PROMOTION

- The BIPM's new website, based on an updated Content Management System and with a new graphic design, was released to the public in April 2021.
- The theme for World Metrology Day in 2021 was "*Measurement for Health*". The poster was translated into more than 30 languages and information on 38 national celebratory events is provided on the WMD website.
- Metrologia's Impact Factor (2020): 3.157.

DIGITAL TRANSFORMATION

- An Application Programming Interface (API) was realized for searching CMCs in the KCDB, now available online, supported by detailed written guidance.

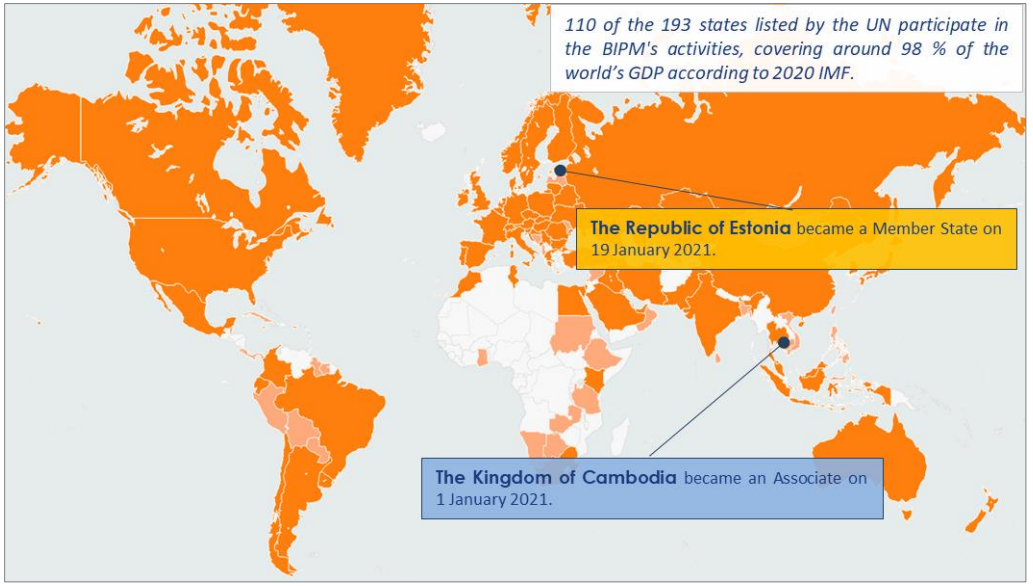
Key figures *(as of 31 December 2021)*

- Member States and Associates

– 63 Member States* and

– 39 Associates of the CGPM
(States and Economies)

**The official term is "States Parties to the Metre Convention"; the term "Member States" is its synonym and used for easy reference.*



- KCDB data

258 Institutes
- 102 National Metrology Institutes
  - *63 Member States*
  - *39 Associates*
- 4 International organizations
  (ESA, IAEA, JRC, WMO)
- plus 152 Designated Institutes

1 735 comparisons
1097 KCs, 638 SCs

25 887 CMCs
Peer-reviewed declarations

I	**Physical Metrology**	
Project	Deliverables	Work performed in the period (1 January 2021 – 31 December 2021)
1. PMD-E1: INTERNATIONAL REFERENCE STANDARD for VOLTAGE		
E1.1: On-site comparisons of Josephson voltage standards (JVSs) *NMI Part.: 4*	1) Bilateral on-site comparisons at dc as part of BIPM.EM-K10.a/b and/or ac (new comparison) with relative uncertainty of 1×10^{-10} (dc) and below 10^{-6} (ac) 2) Maintenance of the transportable Josephson voltage standards, supporting also bilateral comparisons of Zener voltage standards (E1.2) and calibrations of Zener voltage standards for NMIs (E1.3)	• Publication of the measurement report for the BIPM.EM-K10 comparison with MIKES-Finland. • A presentation on the status of the future ac voltage comparison was given at the CCEM WGLF meeting leading to the creation of a task group to support the elaboration of the technical protocol. 14 scientists from 10 NMIs joined the group. An update of the BIPM.EM-K10 protocol with an extension to ac voltages was drafted and this first draft was submitted for review to the task group. • The BIPM/KRISS differential sampling software - for ac voltage comparisons - was updated for the use of a new sampler. A paper presenting the results has been published (Mun-Seog Kim *et al* 2022 *Metrologia* 59 015006). • A pilot study with PTB on differential sampling of ac waveforms took place in December 2021 in the BIPM laboratories. For the first time, a relative difference of a few parts in 10^8 could be achieved for some tested frequencies at the level of 1 V rms using a solid-state source developed at the CMI (Czech Republic). The device was selected to become the BIPM transfer standard for the future comparison protocol. • The NIST delivered a 10 V SNS array in replacement of a similar broken chip. This new array was well characterized in order to determine the optimal working parameters: RF frequency and corresponding power and biasing current.
E1.2: Bilateral voltage comparisons using Zener diode transfer standards *NMI Part.: 4*	a) Bilateral comparisons of Zener voltage standards as part of BIPM.EM-K11.a/b with relative uncertainty of 5×10^{-8} b) Participation in related RMO comparisons to link them to BIPM.EM-K11 c) Maintenance of the BIPM secondary dc voltage standards (Zeners), also supporting the calibration of Zener voltage standards for NMIs (E1.3)	• Publication of the measurement reports for the Zener voltage standard comparisons BIPM.EM-K11 with NSAI-Ireland, BIM-Bulgaria and SMD-Belgium. • Electronics development: the BIPM voltage stabilizer which ensures powering the transfer standards during the transportation phases of the bilateral comparisons BIPM.EM-K11 was improved. • The frequency stability of the Gunn diode providing the microwave radiation for the Josephson Voltage Standard was improved. • The BIPM Zener secondary voltage standards have been re-calibrated against the Josephson voltage standard.
E1.3: Calibrations of Zener diode secondary standards *Calibration for: 10 NMIs (12 certificates)*	1) Calibration of Zener diode secondary standards for NMIs without primary realization and for internal customers (Ionizing Radiation and Kibble balance)	• Calibration of ten secondary voltage standards (SIQ-Slovenia, LPEE-Morocco, DEFNAT-Tunisia, INRiM-Italy, BIPM Ionizing Radiation Department); this is a significant increase compared to the usual demand for this service. • Support for the BIPM Kibble balance team in the metrological verification of two Josephson voltage standards. Study of the variability of the gain of the voltmeter operated in the Kibble balance measurement system.

I	Physical Metrology	
Project	Deliverables	Work performed in the period (1 January 2021 – 31 December 2021)
		• The metrological validation process of the automated Zener calibration setup was completed. The traditional manually operated SIS unit will only be maintained for occasional checks of our batch of primary voltage standards. • Publication of a peer reviewed article presenting the research work on Zener-based secondary voltage standards achieved over the five last years (R. Chayramy *et al.*, *Meas. Sci. Technol.*, 32 (2021) 105019).
2. PMD-E2: INTERNATIONAL REFERENCE STANDARD for RESISTANCE		
E2.1: On-site comparisons of quantum Hall resistance (QHR) standards *NMI Part.: 4*	1) Bilateral on-site comparisons of quantum Hall standards (including new graphene samples) as part of BIPM.EM-K12 with relative uncertainty 1×10^{-9} 2) Providing the basis for the realization of the capacitance unit farad 3) Maintenance of the transportable standard and related measurement chain, also supporting bilateral resistance comparisons using resistance transfer standards (E2.2) and calibrations of secondary standards for NMIs (E2.3)	• Finalization and publication of the measurement report concerning the BIPM.EM-K12 comparison with NMC-A*STAR-Singapore. • A new on-site comparison of QHR standards BIPM.EM-K12 is planned with the LNE, for late 2022. • Characterization tests of two new GaAs QHR devices provided by PTB for ensuring the continuity of the services (two new GaAs samples were provided in 2020 and two others in 2021). They are intended to replace the ageing LEP-514 samples still in use at BIPM. • Testing of two graphene devices developed and provided by PTB. These tests follow those carried out in late 2020 and early 2021 on samples from Graphene Waves (NIST technology). This work is a first step in the realization of a new compact graphene based QHR system which should replace, in time, the current GaAs system. • Characterization of a set of six 1 ohm standards developed by NMIJ and Alpha Electronics, including four prototypes. The main objectives were to assess their stability at short and long term as well as their low frequency dependence. This study was carried out in collaboration with the PTB and the AIST/NMIJ. Very promising results were obtained, and an additional round of characterization measurements is planned for the second part of 2022. It is expected that this work will allow to identify the best 1 ohm transfer standard to be used for on-site BIPM.EM-K12 comparisons. • Maintenance works on the electronics of the transportable 1Hz bridge used for BIPM.EM-K12. In particular, new low frequency room temperature current comparators are being fabricated. • Winding of a new multi-windings superconducting coil intended to replace that of one of the two cryogenic current comparators (CCC) of the BIPM, in collaboration with LNE. The new CCC will allow to ensure the continuity of services in case the currently used CCC would malfunction. • The basis for the realization of the farad from the QHR (E3.1) has been provided in February and July 2021.

I	**Physical Metrology**	
Project	Deliverables	Work performed in the period (1 January 2021 – 31 December 2021)
E2.2: Bilateral resistance comparisons using resistance transfer standards *NMI Part.: 4*	1) Bilateral comparisons of resistance transfer standards as part of BIPM.EM-K13.a/b with relative uncertainty of 5×10^{-8} 2) Participation in related RMO comparisons to link them to BIPM.EM-K13 3) Maintenance of BIPM secondary resistance standards and related measurement chain, also for the calibration of resistance secondary standards for NMIs (E2.3)	• Publication of the measurement reports concerning a BIPM.EM-K13 comparison with INMETRO-Brazil. • Ongoing BIPM.EM-K13 comparison measurements with NPLI-India and CEM-Spain. • Preparation of two BIPM.EM-K13 comparisons with INRiM-Italy and CENAM-Mexico for end 2022-2023.
E2.3: Calibrations of resistance secondary standards *Calibration for: 25 NMIs (150 certificates)*	Calibration of resistance secondary standards for NMIs without primary realizations and for internal customers (Mass, Ionizing Radiation, Kibble balance)	• 37 resistance standards calibrated for 10 NMIs (DEFNAT-Tunisia, EIM-Greece, SIQ-Slovenia, GUM-Poland, LPEE-Morocco, Tubitak UME-Turkey, SMD-Belgium, BFKH-Hungary, INMETRO-Brazil, INPL-Israel) and 2 internal certificates (mass laboratory).
3. PMD-E3: INTERNATIONAL REFERENCE STANDARD for CAPACITANCE		
E3.1: Bilateral capacitance comparisons using capacitance transfer standards *NMI Part.: 4*	1) Bilateral comparisons of capacitance transfer standards as part of BIPM.EM-K14.a/b with relative uncertainty of 5×10^{-8} 2) Maintenance of the measurement systems to derive the capacitance unit from the quantum Hall effect and/or the calculable capacitor, also supporting the calibrations of capacitance secondary standards (E3.2)	• Two realizations of the farad from the ohm in February and July. • Monthly measurements for the surveillance of the capacitance bank of 10 pF capacitors. • Update of the measurement procedure and uncertainty computation of the relative capacitance change with frequency of the BIPM reference standards. • Characterization of 7 BIPM traveling standards in view of a bilateral comparison (BIPM.EM-K14 a & b) to be held in 2022 with the NMIM (Malaysia).
E3.2: Calibrations of capacitance secondary standards *Calibration for: 20 NMIs (110 Certificates)*	1) Calibrations of capacitance secondary standards for NMIs without primary realizations	• 23 capacitance standards calibrated for 6 NMIs (BEV-Austria, SIQ-Slovenia, SASO-Saudi-Arabia, INMETRO-Brazil, MIKES-Finland and SMD-Belgium). 1 Study Note was issued for one standard.
E3.3: ac quantum Hall effect	1) Development of the ac quantum Hall effect into an operational primary standard of impedance,	• No work during this period.

I	Physical Metrology	
Project	Deliverables	Work performed in the period (1 January 2021 – 31 December 2021)
	to reduce the uncertainty of the realization of the capacitance unit 2) Direct comparison of the ac quantum Hall effect and the calculable capacitor, for verification of the validity of the equation for the von Klitzing constant at the 10^{-9} level, supporting the *mise en pratique* for the electrical units	
E3.4: Calculable capacitor	1) Completion of the calculable capacitor as a primary standard for capacitance to consolidate the BIPM measurement capabilities at the highest level and to help curating knowledge in this key technique	• Checking of the alignment of the four main electrodes using specific tools equipped with capacitive probes. The last alignment was carried out in 2017. • New characterization of the probe used to measure the skew of the four electrodes assembly. • Implementation of a modified measuring system to characterize the individual capacitive sensors of the skew probe. • Starting of the improvement of the 2017 alignment using the skew probe. • Verification of the alignment of the main electrodes and preparation of a procedure for the alignment of the interferometer and guard electrode.
4. PMD-M1: MASS DISSEMINATION		
M1.1: Calibration of 1 kg national prototypes and mass standards *Calibration for: 25 NMIs (50 Certificates)*	1) Calibration of existing 1 kg national Pt-Ir prototypes in air or under vacuum. 2) Calibration of 1 kg stainless steel national mass standards, including volume and centre-of-gravity determination, if requested. 3) Monitoring of the mass evolution of the BIPM working standards. 4) Calibration of pressure gauges, as an internal service necessary to support mass calibrations at the required uncertainty, and for other BIPM departments.	• Calibration of 5 stainless steel mass standards for CEM-Spain, MIRS-Slovenia and LATU-Uruguay. • Calibration of 3 Pt-Ir prototypes for DFM-Denmark (n° 48) and CENAM-Mexico (n° 21 & n° 96). • Calibration of the 2 newly fabricated Pt-Ir 1 kg prototypes nos. 113 and 114. • Calibration of the references Pt-Ir 841 and stainless steel submultiples 100ZW2 and 200ZW22 (100 g and 200 g) for the density laboratory. • Determination of volume of two stainless steel standards of MIRS. • Mass values of BIPM working standards for current use monitored and adjusted against working standards for limited use. • Calibration of submultiples from 1 kg to 10 mg. • Calibration campaign for 12 pressure gauges of the Physical Metrology Department and the Chemistry Department. • Calibration of 1 hygrometer from the Physical Metrology Department.
M1.2:	1) Fabrication of 1 kg Pt-Ir prototypes for Member States.	• The fabrication of prototypes no. 113, 114 and 115 is completed. Nos. 114 and 115 will be provided to NIM. A quotation has been issued for no. 113. An additional quotation has

I	**Physical Metrology**	
Project	Deliverables	Work performed in the period (1 January 2021 – 31 December 2021)
Provision of 1 kg Pt-Ir prototypes *Fabrication for: 3 NMIs*	2) Calibration of new 1 kg Pt-Ir prototypes including volume determination.	been issued for a set of sorption artefacts consisting of a prototype (no. 116) and a stack consisting of 8 disks and 21 spacers.
5. PMD-M2: COMPARISONS of REALIZATIONS of the NEW KILOGRAM DEFINITION		
M2.1: Organization of a key comparison of kilogram realizations *NMI Part.: 10*	1) Organization of a periodic CCM key comparison of all available kilogram realizations and participation in the determination of the consensus value, which during the first years after the redefinition will serve as the basis for dissemination for all participants to ensure world-wide uniformity of mass measurements. 2) Ongoing bilateral key comparison of kilogram realizations, linked to (1) 3) Update of the mass values attributed to the ensemble of reference mass standards (ERMS) and the Pt-Ir working standards, traceable to the reference value of the comparison of kilogram realizations.	• The first CCM consensus value for an internationally coordinated dissemination of the kilogram has been determined by the BIPM and implemented by the CCM. Publication of a letter to the editor (S. Davidson *et al.*, *Metrologia* 58 (2021) 033002) • The technical protocol for the second key comparison of kilogram realizations, CCM.M-K8.2021, organized again by the BIPM, has been finalized. • The list of participants has been established. • The first travelling standards arrived at the BIPM in October 2021.
M2.2: Organization of a comparison of calibrations of stainless steel mass standards. *NMI Part.: 15*	1) Organization of a new comparison of stainless steel 1 kg mass standards 2) Participation in related RMO comparisons.	• New comparison of stainless steel standards planned to be organized by the BIPM during 2022/23.
M2.3: Maintaining the ERMS (ensemble of reference mass standards)	1) Link of the ERMS masses with values from realization experiments. 2) Mass comparison of standards within the ERMS.	• No work during this period.
6. PMD-M3: KIBBLE BALANCE. *Developing and maintaining the Kibble balance*		
M3.1:	Achieving a target uncertainty of 2 parts in 10^8 (corresponding to 20 µg at 1 kg) by further improvements of the apparatus and the development of a detailed uncertainty budget.	• Work has continued to investigate and improve the electrical circuit. An unexpected influence of the nanovoltmeter in the PJVS system was observed for two PJVS arrays and confirmed by a study conducted by colleagues from the electricity laboratories. Work will pursue by investigating the electrical grounding of the PJVS and the DVMs for voltage measurement.

I	**Physical Metrology**	
Project	Deliverables	Work performed in the period (1 January 2021 – 31 December 2021)
		• A new switch box has been developed and was integrated in the apparatus. It allowed the simplification of electrical connections and more importantly the disconnection of the nanovoltmeter in the PJVS system from the circuit during voltage measurement. • Work has started to program a microcontroller for developing a current source. • New electronics for position sensors were built and used. • A complete revision of the apparatus alignment is underway. The alignment of the interferometer is finished. Conversion factors and the associated data reduction program for the position sensors are being checked. • A bias due to the use of a commercial rotary switch in the new switch box has been found. A second new switch box based on low emf was consequently built. • Various electrical connection schemes were tested and the most suitable one was identified.
M3.2:	Reengineering of critical mechanical subsystems to enable semi-routine operation.	• New middle and lower parts of the suspension for the mark II of the apparatus have been integrated into the present apparatus. The operation of the ensemble in vacuum was verified. • The design of an equal-arm beam as well as associated actuators and sensors for the mark II Kibble balance apparatus was completed. The ensemble was fabricated at the BIPM mechanical workshop.
M3.3:	Developing software and control system for full operation in vacuum.	• The development is completed for routine operation in vacuum. If needed, further improvements and updates will be implemented.
M3.4:	Develop a capability, in conjunction with NMIs that have a transportable gravimeter, for the determination of gravitational acceleration at the uncertainty level of a few parts in 10^9. This will require absolute gravimeter(s) to be brought to the BIPM from NMIs that have successfully participated in the most recent ICAG, accompanied by the NMI experts, for measurements in the BIPM Kibble balance laboratory.	• No work during this period
M3.5:	Participate in the ongoing comparison of realizations of the kilogram (PMD-M2).	• Mass measurements of the transfer standard for the 2nd key comparison of the kilogram realizations were carried out from 22 October to 08 November. • Additional measurements were performed to evaluate various uncertainty components.

I	**Physical Metrology**	
Project	Deliverables	Work performed in the period (1 January 2021 – 31 December 2021)
M3.6:	Carry out a design study for a Kibble balance, taking advantage of the re-definition of the kilogram to realize directly masses below 1 kg, with smaller uncertainties than at present.	• No work during this period.

II	Time Metrology	
Project	Deliverables	Work performed in the period (1 January 2021 – 31 December 2021)
1. TIME-U1: GENERATION of TAI/UTC, STABLE and ACCURATE INTERNATIONAL REFERENCE		
U1.1: Computation of UTC and KC for Time and Frequency transfer *Participating laboratories: 80 (2017)*	Monthly provision of the international reference time scales TAI, UTC, and the terrestrial Time (TT), continuously improving their metrological quality. This is obtained by computing the differences between UTC/UTCr and the local real time realizations UTC(*k*) of the contributing laboratories. Results are published in the monthly BIPM *Circular T*, the weekly bulletin of the UTCr, and providing data to the KCDB for the key comparison CCTF-K001.UTC. The process to obtain UTC and its validation is part of the BIPM Quality System. The Department also issues an annual report with a summary of the results.	• Regular production of monthly UTC, CCTF-K001.UTC, and weekly Rapid UTC. • Computation of TT(BIPM20). • Several PSFS data available, and used for the steering of TAI https://webtai.bipm.org/database/show_psfs.html • Annual report 2020 published • QMS update to ISO 17025:2017 and impact on the UTC computation procedure • New Asia Pacific TWSTFT in progress. A switching to a new satellite ensures better stability. Tests on going • EU USA TWSTFT: Change of satellite and successive change of transmission: transfer of calibration and revaluation of the calibration delays carried out ensuring continuity of all links. New participating station began transmitting in September • Selection process for one new physicist and training of the new SW Engineer for the department • Support to the use of new primary and secondary frequency standards in UTC along the roadmap to the redefinition of the second https://www.bipm.org/en/-/2021-12-21-record-tai
U1.2: Development and optimization of the UTC computation	The continuous improvement of UTC and related products is based on the development of appropriate SW tools and HW reliability. The goals of this WP are mostly based on: – Automatization of the computation system augmenting the automatic checks on input and output data to improve the reliability of the results. – Use of a redundant and secure ensemble of servers based on virtualization technology. – Use of data base structure for the time transfer and calibration data to provide user-friendly access to the results to the contributing NMIs.	• Development of the project of a new department IT system based on Virtual Machine to ensure the separation and insulation of the IT services, initial migration of the SW routines for the production of UTCr • Development of the Front End for the easy visualization of the availability of the UTC input data including time transfer and clock data from UTC labs and external data from IGS. • Update of the GNSS calibration web site with the results for GPS and Galileo repeated calibration campaigns https://webtai.bipm.org/database/calib.html • Development of a test API based on the UTC data base giving access to machine readable data regarding UTC and rapid UTC. Initiation of an API Newsletter https://webtai.bipm.org/api/ • Participation to BIPM WG on scientific SW validation contributing to the BIPM SW validation guideline • Participation to the BIPM WG on Digitalization.

II	Time Metrology	
Project	Deliverables	Work performed in the period (1 January 2021 – 31 December 2021)
2. TIME-U2: IMPROVED ALGORITHMS for TIME SCALE and TIME TRANSFER DATA PROCESSING		

ALGORITHMS	The algorithms developed, maintained, and continuously improved by the Time Department are devoted to:
	– the ensemble time scale formation,
	– the corrected processing of the time transfer measures,
	– the steering by the use of primary and secondary frequency standards.
	The goals are an algorithm for outlier and faults detection, monitoring of the data flow and link comparison, redundant links, multi-constellation GNSS time transfer, as well as algorithms treating each clock with adapted and modern statistical tools. The contribution of a ²secondee would be fundamental to ensure the necessary progress of these activities.
	The use of a GIT* laboratory capability within the frame of the TWSTFT WG so that software for software defined receiver (SDR) measurement technique can be developed through a collaborative effort with leading NMIs. This shared configuration will then be validated by a joint BIPM/NMI team and be made available for download as a service to NMIs (and other UTC time laboratories). Opportunities to use the capability for training and equipment monitoring will also be explored.
	*GIT is a free and open source distributed version control system
		• Further analysis of the algorithm for UTC computation extended to redundant link (Panfilo *et al* 2020 *Metrologia* 57 065011) to evaluate the use of redundant optical fibre links in the measurement of PSFS. Results presented at the IEEE IFCS/EFTF congress: Petit G., Panfilo G., Improving UTC with redundant time/frequency links, IFCS-EFTF 2021 (one-page summary)
		• Statistical Analysis of the predictability of several families of H-Masers to improve the long-Term Stability of UTC. Results presented at the IEEE IFCS/EFTF congress: J. Milton, G. Panfilo, – EFTF-IFCS 2021
		• Development and use a new estimation technique for the reference frequency values of PSFS and their correlation with the Joint CC CCTF WG on frequency standards based on graph theory
		• Work in progress on the update of Circular T sec 4 on the GNSS dissemination of UTC, extended to Beidou and Galileo systems. Defraigne P., Pinat E., Petit G., "Validation of the UTC information broadcast in the navigation messages by all GNSS", in proceedings IFCS-EFTF 2021
		• Development of the capacity to compare clocks by the Integer PPP technique, also used to validate other very precise time and frequency methods https://www.bipm.org/en/-/2020-optical-clocks. Related papers:
		  • Sekido M et al. (2021) A broadband VLBI system using transportable stations for geodesy and metrology - An alternative approach to the VGOS concept. J. Geodesy, 95, 41 https://doi.org/10.1007/s00190-021-01479-8 .
		  • Petit G. (2021) Sub-10-16 accuracy GNSS frequency transfer with IPPP. GPS Solutions https://doi.org/10.1007/s10291-020-01062-2

3. TIME-U3: CALCULATION and DISSEMINATION of RAPID UTC		
RAPID UTC	To meet the requirements of the NMI time labs and of other UTC users, a rapid approximation of UTC, called rapid UTC, is available weekly based on a	• UTCr has been published without interruption every Wednesdays, the offset to UTC remains within +/- 2 ns.

II	Time Metrology	
Project	Deliverables	Work performed in the period (1 January 2021 – 31 December 2021)
Participating laboratories: 57 (2018), 2023 target is to grow by 10 %	subset of data. The automatization of the process and a reliable anomaly detection are in this case still more important and will be pursued in this WP, evaluating the possibility for a more frequent evaluation of the time scale. To be in pace with emerging user communities, as for example the GNSS navigation and timing systems, the Time Department will investigate the impact of reducing the delay in the publication of UTC and UTCr.	• The SW routines for the computation of UTCr are under migration on the new IT service with the aim to make the automatization of the process more robust and scalable
4. TIME-D1: CHARACTERIZATION of DELAYS in TIME TRANSFER EQUIPMENT OPERATED in TAI/UTC CONTRIBUTING LABORATORIES		
D1.1: Maintenance of BIPM GNSS travelling receivers and procedures for calibration	1) Characterization, study, and experimental tests of equipment compatible with those operated in NMIs. 2) Reliable/redundant travelling and fixed-reference standards. 3) Guidance documents and support for contributing NMIs. 4) Technical protocols for calibration. 5) Methods of calibration aimed at improving the time link uncertainty, which remains the largest component of the uncertainty of *UTC- UTC(k).* 6) Maintaining a time lab supporting test and calibration of high accuracy microwave link. 7) Provision of a frequency reference to the other BIPM labs. The dissemination of this frequency signal and the related internal calibrations are part of the BIPM Quality System.	• Work with the CCTF WG on GNSS to determine the BIPM G1 reference point for the calibration of GPS and Galileo • Validation of the calibration capacity of the new BIPM calibration box B4TS aiming to G1 and also TWSTFT calibrations. Result presented at the IEEE IFCS/EFTF congress F. Meynadier, G. Petit, L. Tisserand, G. D. Rovera, J. Achkar, P. Uhrich, F. Riedel, T. Thai, I. Sesia, C. Courde, "Validation of a New BIPM Calibration System Based on GNSS Receivers for TWSTFT Links", 2021, EFTF-IFCS 2021 • Maintenance of the BIPM traveling equipment B3TS for the 2020 Group 1 calibration trip. • Work continued on absolute delay measurement of GNSS receivers, in collaboration with Pascale Defraigne of ORB, chair of the CCTF WG on GNSS. The absolute calibration of delays for the BDS3 signals has been carried out by ESTEC for one BIPM receiver (BP27). As a result, all BIPM receivers able to track the four GNSS can now be traced to an absolute calibration measurement. • Absolute calibration available through BIPM receivers is transferred to selected receivers in G1 laboratories that will be used for Circular T section 4.
D1.2: Realization of delay measurement campaigns for pivot laboratories (G1 labs)	This project ensures the calibration trips by GNSS receiver to the labs belonging to GNSS Group 1 or to other networks of labs. The different steps are: – To organize the GNSS measurement campaigns (requiring the shipping of the BIPM travelling	• Extension of the G1 GNSS calibration campaign to the Galileo system measurement. Calibration results are now stored in https://webtai.bipm.org/database/calib.html for GPS and Galileo • 2020 Group 1 visit to EURAMET G1 laboratories (OP, PTB, ROA) and to SIM G1 laboratories (NIST, USNO). Visit to COOMET G1 (SU) in preparation.

II	Time Metrology	
Project	Deliverables	Work performed in the period (1 January 2021 – 31 December 2021)
	system without staff) to each of approximately ten contributing laboratories (G1 labs), a number that should expand with new RMOs. The whole process involves several circulating trips and is repeated every other year. – to calibrate the TWSTFT networks by travelling GNSS receivers and by setting up additional dedicated travelling equipment with the aim to reach the best possible achievable uncertainty. – to check the receiver conditions and measure internal delays before and after the circulation. – to carry out the data analysis and issue the calibration report.	• Publication of all results of the 2020 G1 trip and implementation in the department database. • Update the Calibration Guidelines to version 4.0 available at • https://webtai.bipm.org/ftp/pub/tai/publication/gnss-calibration/guidelines/...
D1.3: Coordinating with the RMOs for GNSS campaigns of G2 laboratories (labs which are not pivot labs) and linking results to the BIPM G1 reference	1) Provision of Guidelines. 2) Regular assessment of the values of the Type B uncertainty. 3) Validation of the G2 calibration reports and maintenance of the database. 4) Realization of differential calibration at the BIPM for G2 labs outside RMOs.	• Complement the Calibration Guidelines by a guide " How to get GNSS calibration for UTC(k) laboratories " available online. • Processing and validation of 15 Group 2 reports. Results introduced in the database.
5. TIME-O1: USE of VERY ACCURATE OPTICAL FREQUENCY STANDARDS - SECONDARY REPRESENTATIONS of the SECOND		
O1.1: New time and frequency transfer techniques in TAI/UTC. Possible redefinition of the SI second and TT	1) Develop an operational algorithm for the analysis and comparison of optical frequency standard measures to estimate the relative frequency values. 2) Study, develop, and make operational new algorithms for the processing of new and innovative time and frequency measures (optical fibres, 3-way by satellite). 3) Collaborate with NMIs and the CCTF for standardization of measurement process, data format; data treatment.	• Support to the Joint CCL CCTF WG on Frequency standards in the evaluation of the updated reference values for the secondary frequency standards by the development of a completely independent algorithm for the estimation of frequency values and their correlation. Estimation of all the possible correlations between the available measurements as input to the evaluation algorithms • Support to the CCL and Joint CCL -CCTF WG on the digitalization of reference data for the realization of the metre and the second. • Active collaboration with the CCTF on the redefinition of the second through the Task Force on the Roadmap to the redefinition of the second and its 3 subgroups (see Support to CCTF). • Follow the work of European collaboration TIFOON " Time and Frequency over Optical Networks " and project CLONETS " CLOck NETwork Services" in participating and contributing to their workshops.

II	Time Metrology	
Project	Deliverables	Work performed in the period (1 January 2021 – 31 December 2021)
	4) Promote the refinement of the Earth gravity potential as necessary for the comparison of optical frequency standards. 5) Contribute to the discussion on the redefinition of the second.	
O1.2: Optimal use of optical standard measurements in TAI/UTC	New optical standards as well as new time and frequency comparison in the optical domain call for an update of the TAI/UTC data processing to optimize the contribution of these new measures. To this aim, the Time Department need: (a) to develop the correct statistical treatment of measures that may have peculiarities (dead time, long period of missing data, only frequency comparison…); (b) to adapt the TAI algorithm for the optimal introduction of the optical frequency standard measurements; (c) to study new optical transfer techniques and their technical constraints with the aim to appropriately estimate the uncertainty; (d) to set up calibration techniques and guidelines. The feasibility for the BIPM time lab to be connected to the network of optical fibres under construction by the NMIs will be explored. This would provide the possibility to: (a) validate the usual GNSS calibrations by independent and more accurate technique, (b) be connected to several of the new optical standards under development and to different UTC(*k*) time scales (c) provide training on the technologies of the future and explore the possibility for providing	• Study the effect of improved (optical) time links on the uncertainty of [UTC-UTC(k)] and on the use of optical standards in TAI steering. In Petit G., Panfilo G., Improving UTC with redundant time/frequency links, IFCS-EFTF 2021 • Update of the Sec 3 of the Circular T with more details on the uncertainty and deadtime of the PSFS measurements in collaboration with the CCTF WG on PSFS. • Following the development of the ACES-PHARAO mission to evaluate the possibility of future use in UTC for clock comparisons • The study of a possible fiber connection with OP to practice White Rabbit time transfer is on halt since beginning of the sanitary measures. Inspection on the site and negotiation meeting with fiber providers will restart in 2022

II	Time Metrology	
Project	Deliverables	Work performed in the period (1 January 2021 – 31 December 2021)
	a hub for international PSFS comparison for NMIs. These additional activities require additional effort that the BIPM staff could ensure only at a very basic level. To face the new challenges with appropriate resources and optimizing the use in TAI/UTC, the support of a full time secondee is necessary both in the data treatment, and in the set-up of the experimental fibre connection. In case this should not be available, only a minimal, un-optimized, and incomplete activity can be ensured.	

III	Chemical Metrology	
Project	Deliverables	Work performed in the period (1 January 2021 – 31 December 2021)
1. CHEM-G1: SURFACE OZONE AND AIR QUALITY GAS STANDARD COMPARISONS Coordination of comparisons to determine and improve the international equivalence of gas standards for air quality monitoring		
G1.1 *NMI Part.: 20*	20 ozone standards bilateral comparisons as part of BIPM.QM-K1 coordination (2020-2023), based on the unique triad of standards at the BIPM, which will maintain consistency of calibration services for surface ozone measurements for local, regional, national and global air quality monitoring networks.	• 2 bilateral comparisons performed in BIPM laboratories for ISCIII (Feb. 2021) and CHMI (Sep. 2021). • 1 key comparison report published for METAS (July. 2020).
G1.2: *NMI Part.: 10*	Update of SRP electronics system for National Ozone Standards, in collaboration with the NIST, enabling NMIs to extend the lifetime of their ozone standards (Note, costs included relate to upgrade and maintenance of the BIPM systems only, validation of upgraded standards included in BIPM.QM-K1)	• New SRP control software provided by NIST installed and validated at BIPM • Full upgrade of the three SRPs maintained by the BIPM completed with negligible impact on comparability demonstrated. • Revalidation of BIPM owned SRP27, 28 and 31, with restart of the BIPM.QM-K1 comparison. • Construction of electronics boxes for two additional SRPs owned by the BIPM completed.
G1.3: *NMI Part.: 15 (Measurements started in 2016-2019 BIPM Work Programme)*	Coordination of reactive gas/air quality comparisons (NO_2, HNO_3 and HCHO impurity comparison and spectroscopy studies), based on state of the art dynamic standard reference facilities at the BIPM, enabling NMIs to demonstrate equivalence of their standards for air quality and vehicle emission verification measurements.	• CCQM-K74.2018 (NO_2 in nitrogen) comments on Drafts B version received and treated. The final report was reviewed and published in the KCDB. • The CCQM-P172 (HNO_3 spectroscopic methods) Draft A report prepared and presented to participants in June 2021. Raw measurement data received from participants and 80% reanalysis of data completed. • A 5-month stability study on four NO_2/N_2 standards completed in from June 2021, as follow up analysis to CCQM-K78.2018.
2. CHEM-G2: INTERNATIONAL REFERENCE FACILITY for COMPARISON of STANDARDS and SCALES for CLEAN AIR Coordination of comparisons to determine and improve the international equivalence of radiative forcing gases		
G2.1: *NMI Part.: 20*	Coordination of BIPM.QM-K2 on Carbon dioxide in air (2020-2023), based on a unique manometric reference comparison facility maintained at the BIPM, providing an independent absolute analytical reference method for on-demand comparisons of gravimetrically prepared NMI standards for greenhouse gas and emissions measurement calibrations.	• BIPM CO_2-PVT (manometric) reference facility further improved by replacement of remaining stainless-steel surfaces with Silconert to minimize adsorption of CO_2. • 3 models of cryogenic traps for CO_2 extraction tested in the CO_2-PVT facility to reach close to 100% efficiency, validated by series of measurements of 5 CO_2 in air standards. • Residual CO_2 adsorption estimated during series of measurements with varying pressures on 5 known CO_2 in air standards • Method reproducibility at the 0.02 µmol/mol level demonstrated.

III	Chemical Metrology	
Project	Deliverables	Work performed in the period (1 January 2021 – 31 December 2021)
G2.2: *NMI Part.: 15*	Completed homogeneity and stability studies on blended mixtures and coordination of CCQM-P204 on isotope ratios in carbon dioxide, and method development for reduced uncertainties, based on BIPM's high accuracy flow and cryogenic trapping system and optically based IRIS facility in collaboration with IAEA, demonstrating the state of the art in equivalence of CO_2 isotope ratio standards for atmospheric and point of origin measurement applications.	• Method to measure and calibrate the isotope ratios by IRMS in aliquots developed at BIPM and validated on aliquots prepared in 2019 and 2020 • Calibration hierarchy of IRMS measurements to the international scale VPDB implemented via primary, secondary and working standards using 6 L canisters with gas value assigned by the IAEA • 120 aliquots filled with pure CO_2 using the BIPM SIRGMGEN system at four different isotope ratios; 80 distributed to CCQM-P204 participants, 12 to the co-pilot laboratory (IAEA) and 28 kept at BIPM. • 12 of the CCQM-P204 aliquots measured by IRMS to demonstrate homogeneity and reproducibility of the preparation system.
G2.3: *NMI Part.: 12*	Developed facility and methods for isotope ratio value assignment of CO_2 in air standards and coordination of CCQM-Pxx (2023) on isotope ratios in carbon dioxide, based on lowest uncertainty mass spectrometric and optically based measurements techniques at the BIPM, demonstrating equivalence of scale based isotope ratio measurements and standards and relationship to SI traceable values.	• Construction of automated cryogenic extraction system for CO_2 in air samples completed and proof of concept demonstrated. • Standards for system validation ordered. • 9 months of virtual visiting scientist contract completed with finalization of IRMS CO_2 pure gas method development. • One month training programme of BIPM staff member on carbonate reaction systems at LSCE (France) completed. • Contribution to paper on 'Minimum requirements for publishing HCNOS stable isotope delta results', submitted to *Pure and Applied Chemistry*
3. CHEM-G3: INTERNATIONAL REFERENCE FACILITY for COMPARISON of STANDARDS AND SCALES for RADIATIVE FORCING GASES Coordination of comparisons to determine and improve the international equivalence of gas standards for radiative forcing gases.		
G3.1: *NMI Part.: 20 + 16 (Measurements started in 2016-2019 BIPM Work Programme)*	Completion of key comparison on nitrous oxide and coordination of methane in air standards comparison (CCQM-K82.2023), based on dedicated greenhouse gas standard comparison facilities at the BIPM with minimized analytical uncertainty to provide demonstration of continued improvement in the accuracy of radiative forcing gas standards world-wide for atmospheric monitoring.	• CCQM-K68.2019 (N_2O in air): participants' final measurements results received in February, Draft A circulated early April; three virtual meetings held with participants in May, June and November to discuss the results. • Collaboration with NIST (A. Possolo) undertaken to include an additional variance in the results reflecting difficulties for participants to best estimate the purity of the gaseous matrix (synthetic air); alternative consensus KCRV presented in the November 2021.
G3.2:	Developed methods with reduced uncertainties for Greenhouse Gas comparisons, based on the improvement of cryogenic separation facilities for	• Optimised setup for efficient cryogenic separation of CO_2 from air fully validated in the CO_2-PVT facility

III	Chemical Metrology	
Project	Deliverables	Work performed in the period (1 January 2021 – 31 December 2021)
	greenhouse gases and their quantitative operation in sample preparation for greenhouse gas mole fraction and isotope ratio measurements.	• 6 videoconferences held with a CCQM GAWG members to establish the CCQM-Task Group on Greenhouse Gas Scale Comparisons, leading to the first official meeting on 4 October 2021
4. CHEM-O1: SMALL MOLECULE ORGANIC PRIMARY REFERENCE COMPARISONS (PURE MATERIALS) Coordination of comparisons to determine and improve the international equivalence of organic primary calibrators for clinical chemistry and laboratory medicine, food analysis, environmental analysis, forensics and pharma.		
O1.1: *NMI Part.: 25(Measurements started in 2016-2019 BIPM Work Programme)*	Completion of bisphenol A purity comparison CCQM-K148.a (non-polar organic (< 500 Da), with mass-balance and qNMR value assignment at the BIPM, and homogeneity and stability analysis, providing a core comparison enabling NMIs to demonstrate capabilities and continued improvement in providing SI traceability for small molecule low polarity organic analytes.	• Final Report approved by CCQM WG Chairs in March 2021 and published in the KCDB in May 2021.
O1.2: *NMI Part.: 25*	Coordination of CCQM-K148.b (polar organic (< 500 Da) with mass-balance and qNMR value assignment at the BIPM, and homogeneity and stability analysis providing a core comparison enabling NMIs to demonstrate capabilities and continued improvement in providing SI traceability for polar small molecule organic analytes.	• Oxytetracycline agreed as analyte for comparison • LC-UV method for quantification of impurities validated. • Material homogeneity studies completed: LC-UV (related impurities), IC (chloride content) and KFT (water). • qNMR studies on material stability in solution completed. • Solid material stability studies completed
O1.3: *NMI Part.: 25*	Coordination of CCQM-K148.c organic purity (500 Da to 1000 Da) and method development, with mass-balance and qNMR value assignment at the BIPM, and homogeneity and stability analysis, providing a core comparison enabling NMIs to demonstrate capabilities and continued improvement in providing SI traceability for larger small molecule analytes, together with the extension in methods for their characterization.	• Project to start in 2022.
5. CHEM-O2: SMALL MOLECULE ORGANIC PRIMARY REFERENCE COMPARISONS (CALIBRATION SOLUTIONS) Coordination of comparisons standards and methods for organic calibrants.		
O2.1: *NMI Part.: 25*	Coordination of the calibration of solution comparison CCQM-K78.b (Multi-component non-	• Solution of trifluarin and mythoxychlor used as sample for comparison • Development GC-MS method for sample analysis completed

III	Chemical Metrology	
Project	Deliverables	Work performed in the period (1 January 2021 – 31 December 2021)
	polar), based on BIPM gravimetrically prepared calibration solutions with multi component non-polar analytes, with the mass fractions of primary reference materials quantified within the BIPM purity measurement facilities, providing a core comparison for non-polar organic calibration solutions for NMIs.	• Homogeneity and stability of ampouled solutions completed. • Independent confirmation of gravimetric values by GC-MS method completed
O2.2: *NMI Part.: 5*	Developed and published reference data for qNMR internal standards, based on BIPM's dedicated qNMR facility and in collaboration with NMIJ providing published reference data on qNMR internal standards, enabling the extension of the use of qNMR to accurate measurements with ^{19}Fnuclei, and extending the scope of applicability of qNMR for SI traceable measurements on organic analytes, and support for NMI measurement services and their comparisons.	• Internal Standard reference documents on two ^{19}F qNMR materials 30% complete. • Comparison study of *ab initio* modelling software for purity assessment extended using BIPM qNMR data on DMTP/BTFMBA and completed • Characterization of benzoic acid for ISRD development initiated with NIM China, and 25 % completed.
6. CHEM-O3: LARGE MOLECULE ORGANIC PRIMARY REFERENCE METHOD DEVELOPMENT and COMPARISONS Coordination of comparisons to determine and improve the international equivalence of organic primary calibrators for Clinical Chemistry and Laboratory Medicine, Forensics and Pharma		
O3.1:	Developed and published methods for the characterization of large molecule primary calibrators, based on high resolution mass spectrometry facilities at the BIPM, extending the application of mass spectrometric methods for the identification and quantification of structurally related impurities in peptide calibrators that are future candidates for comparisons to underpin NMI measurement capabilities.	• Visiting scientist secondment from NPL on C3-triskelion completed and poster of work completed presented as CIM 2021 • Draft of paper on compositional analysis of C3-triskelion completed • Study on prioritization of future peptide comparisons presented at the CCQM-PAWG meeting • Invited keynote lecture presented on RMS for Protein Biomarkers at both BCEIA Beijing 2021 plenary and Chemical Metrology and Reference Material sub-session.
O3.2: *NMI Part.: 15*	Completion of purity key comparison CCQM-K115.c C-HbA1c hexapeptide purity, CCQM-K115 repeat on HbA0 hexapeptide purity and CCQM-K115.b Oxytocin, based on mass-balance and protein impurity corrected amino acid analysis characterization performed at the BIPM, providing a core comparison of capabilities for value	• External publication of oxytocin methodology developed for CCQM-K115.b published in *Anal Bioanal Chem*. • Comparison measurement results of CCQM-K115.c/P55.2.c (HbA1c hexapeptide (GE) purity) presented and individually discussed in video-conference with KCRV agreed by PAWG supporting the 13 NMI participations. Draft B reports 75% completed.

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Project	Deliverables	Work performed in the period (1 January 2021 – 31 December 2021)
	assignment of primary reference material straight chain peptides with molecular weights smaller than 5 kDa at NMIs, and underpinning reference measurements systems for glycated hemoglobin and their development for diabetes diagnosis and patient monitoring.	• Comparison measurement results of CCQM-K115.2018/P55.2.2018 (HbA0 hexapeptide (VE) purity) presented and individually discussed in video-conference with KCRV agreed by PAWG supporting the 14 NMI participations. Draft B reports 75 % completed.
O3.3: *NMI Part.: 15*	Coordination of CCQM-P216 on SARS-CoV-2 antibody quantification with NIM and NRC in response to the coronavirus pandemic. Method development for CCQM-K115.d Primary peptide calibrator (5 kDa to 10 kDa) large organic molecule primary calibrator comparison, based on mass-balance and protein impurity corrected amino acid analysis characterization performed at the BIPM, providing a core comparison of capabilities for value assignment of primary reference material peptides with molecular weights greater than 5 kDa, cross-links and post-translational modifications for NMIs, and underpinning reference measurements systems for protein diagnostics.	• 3 video conferences held with the CCQM SARS-CoV-2 antibody quantification pilot group to finalize the protocol and planning of the second series of CCQM-P216 coordinated by NIM, with BIPM and NRC. • First series of method development activities for amino acid and peptide tryptic digest analysis of monoclonal antibody material completed at BIPM and BIPM CCQM-P216 results submitted. • Report on CCQM-P216 on SARS-CoV-2 antibody quantification revised and published in the KCDB. • Second series of method development activities for size-exclusion chromatography (SEC) and peptide tryptic digest analysis of monoclonal antibody material completed at BIPM and BIPM CCQM-P216 results submitted. • External oral presentation of qNMR characterisation of peptide calibrators SARS-CoV2 IgG monoclonal antibody work at the CIM 2021. • External publication qNMR characterisation of peptide calibrators SARS-CoV2 IgG monoclonal antibody work submitted to *Measurement Science and Technology.* • Collaboration agreement for Parathyroid hormone (PTH) method development and comparison established with NRC and NIM. Sourcing of PTH materials started.

IV	Ionizing Radiation Metrology	
Project	Deliverables	Work performed in the period (1 January 2021 – 31 December 2021)
1. IR-D1: INTERNATIONAL REFERENCE SYSTEM for X-RAY DOSIMETRY Underpinning the international equivalence of national standards for radiotherapy, diagnostic x-rays, mammography and radiation protection, through the provision of comparisons and calibrations.		
D1.1: *NMI Part.: 16 (i.e. 4 per year)*	Bilateral comparisons (BIPM.RI(I)-K2, -K3, -K7) using high-stability (0.02 %) reference x-ray beams and high accuracy and stability primary standards (0.2 % for air kerma).	• All requested comparisons have been performed corresponding to 5 NMI participations in 2021: K2 and K7 for GUM (Poland); K2, K3 and K7 for BFKH (Hungary). • 4 comparison reports were published in 2021: K3 (GUM-2021, VNIIM-2020, ARPANSA-2020) and K7 (NMIJ-2020).
D1.2: *NMI Part.: 20 (i.e. 5 per year)*	Characterization and calibration of national standards, on request.	• All requested calibrations and corresponding certificates have been completed corresponding to 2 NMI participations in 2021: C3 and C7 for CCRD (Argentina).
D1.3:	Quality assurance of the BIPM primary standards for air kerma and absorbed dose to water, to confirm the long-term stability.	• Quality assurance checks continued all through the year, despite working restrictions.
D1.4:	Quality assurance and continual improvement of the BIPM international reference x-ray beam facilities.	• A new medium energy x-ray generator has been installed and validated (see IR-D4). • Improved radiation protection to meet new recommendations.
2. IR-D2: INTERNATIONAL REFERENCE SYSTEM for GAMMA-RAY DOSIMETRY Underpinning the international equivalence of national standards for radiotherapy and radio-sterilization, through the provision of comparisons and calibrations.		
D2.1: *NMI Part.: 12 (i.e. 3 per year)*	Bilateral comparisons (BIPM.RI(I)-K1, -K4, -K5) using the BIPM ^{60}Co reference beam facility and high accuracy and stability primary standards (0.4 % for absorbed dose and 0.2 % for air kerma).	• All requested comparisons have been performed corresponding to 3 NMI participations in 2021: K1 and K4 for BFKH (Hungary) and K4 for NIM (China). • 6 comparison reports were published in 2021: K1 (GUM-2020, ARPANSA-2020, BEV-2020) and K4 (GUM-2020, ARPANSA-2020, BEV-2020).
D2.2: *NMI Part: 25 (i.e. about 6 per year)*	Calibration and characterization of national standards, on request.	• All requested calibrations and corresponding certificates have been completed corresponding to 4 NMI participations in 2021: C1 and C4 for CIEMAT (Spain), C1 and C4 for CRRD (Argentina).
D2.3:	Quality assurance of the BIPM primary standards for air kerma and absorbed dose to water, to confirm the long-term stability.	• Quality assurance checks continued all through the year, despite working restrictions.
D2.4:	Quality assurance and continual improvement of the BIPM international reference gamma-ray beam facility.	• No changes to the facility during this period.

IV	Ionizing Radiation Metrology	
Project	Deliverables	Work performed in the period (1 January 2021 – 31 December 2021)
3. IR-D3: INTERNATIONAL REFERENCE SYSTEM for HIGH ENERGY PHOTONS Underpinning the international equivalence of national standards for high energy photons to meet the expanding need from the use of clinical linear accelerators for radiotherapy, through the provision of comparisons and calibrations.		
D3.1: *NMI Part.: 14 (i.e. about 4 per year)*	Bilateral comparisons (BIPM.RI(I)-K6) using the BIPM off-site facility at DOSEO, with the BIPM absorbed dose standard and high-stability beam monitoring system.	• All requested comparisons have been performed corresponding to 1 NMI participation in 2021 for K6: PTB (Germany). • One K6 comparison report was published in 2021: LNE-LNHB-2020
D3.2: *NMI Part: 12 (i.e. 3 per year)*	Characterization and calibration of national standards, on request.	• All requested calibrations and corresponding certificates have been completed corresponding to the IAEA and 1 NMI participation in 2021: DTU (Denmark).
D3.3:	Quality assurance of the BIPM absorbed dose standard (graphite calorimeter and transfer instruments) to confirm their long-term stability.	• Quality assurance measurements were completed for the BIPM reference standards in the DOSEO facility. • Supporting calibrations for DOSEO in the BIPM Co-60 facility; three were made for the PTB and two for the IAEA.
D3.4:	Quality assurance and continual improvement of the measurement systems used at the DOSEO/BIPM high-energy photon beam facility.	• Validation and tests of a second graphite calorimeter core. • Improved mechanical arrangement for chamber positioning in water.
4. IR-D4: TOWARDS A NEW REFERENCE STANDARD for STATE-OF-THE-ART RADIOTHERAPY MODALITIES Preparations for the development of a new primary standard to meet future requirements for radiation dosimetry (for example, hadron beam dosimetry at an out-sourced facility, electron calorimetry, x-ray brachytherapy).		
D4.1:	Maintain the existing medium energy x-ray service (this involves installing a new x-ray generator and tube). Report on an investigation into future requirements for radiation dosimetry, identifying the priorities for the long term, taking into account feedback from NMIs and potential growth areas.	• New x-ray generator installed and commissioned. • Re-characterization of the absorbed dose to water standard for medium-energy x-rays following the change of the generator (report presented to the CCRI(I)).
D4.2:	Specification, detailed design and modelling of a new reference standard for the priority identified.	• Design, construction and installation of a new automated calibration bench and x-ray tube support; the support system for the new x-ray tube includes collimator, shutter and automated filter wheel. • Installation of the new x-ray tube and initial tests with the new generator.

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Project	Deliverables	Work performed in the period (1 January 2021 – 31 December 2021)
		• Installation and initial testing of new optical and mechanical devices for accurate positioning of the standard and instruments under calibration. • Design of a new primary free-air chamber in progress; study of electric field homogeneity under various design scenarios.
5. IR-D5: INTERNATIONAL REFERENCE SYSTEM for RADIATION PROTECTION DOSIMETRY (^{137}Cs) Underpinning the international equivalence of national standards for radiation protection dosimetry using an off-site ^{137}Cs facility, through the provision of comparisons and calibrations.		
D5.1: *NMI Part.: 16*	Bilateral comparisons (BIPM.RI(I)-K5) using a BIPM-characterized and operated facility (to be restarted once the external facility is available) and high accuracy and stability primary standards (0.3 %).	• An agreement had been reached with the IAEA in the previous programme to establish the BIPM-K5 service using a new ^{137}Cs irradiator at the IAEA Dosimetry Laboratory. Installation at the IAEA of the irradiator was delayed due to the pandemic and the re-start of this service at IAEA has been consequently postponed until the end of 2022. • The instrumentation needed has been purchased.
D5.2: *Calibration for NMIs: 20*	Characterization and calibration of national standards, on request.	• No progress
D5.3:	Quality assurance and continual improvement of the BIPM primary standards, and the associated ancillary equipment.	• No progress
6. IR-R1: INTERNATIONAL REFERENCE SYSTEM for GAMMA-EMITTING RADIONUCLIDES (SIR / SIRTI) Provision of on-demand capability for bilateral comparisons of gamma-emitting radionuclides for applications in nuclear medicine, the nuclear industry, nuclear physics, environmental protection, radiation protection and nuclear forensics.		
R1.1: *NMI Part.: 25 (i.e. about 6 per year)*	Bilateral comparisons (BIPM.RI(II)-K1) of national standards of long lived gamma emitting radionuclides using the high precision, high stability, SIR ionization chambers (reproducibility better than 0.02 %).	• All requested comparisons have been performed corresponding to 12 NMI participations in 2021: Co-60 (ENEA, NPL, NIM, NRC, POLATOM, LNE-LNHB, LNMRI), Ac-225 (POLATOM), I-123 (PTB), Co-57 (CMI), Ra-223 (POLATOM), Ge-68 (NIM). • 10 reports of K1 comparisons were published in 2021 for the following radionuclides: Ac-225 (PTB-2020), Tb-161 (IRA-2019), Co-60 (PTB-2017, TAEK-2018 and, separately, VNIIM-2019), Ga- 67 (PTB-2010 and NIST-2010), Ra-223 (NPL-2014, PTB-2014 and LNE-LNHB-2018), Ag-110m (PTB-2015), Cd-109 (LNE-LNHB-2012), Gd-153 (NIST-2020), Sr-85 (PTB-2018)
R1.2: *Participating NMIs: minimum of two per*	On-site bilateral comparisons (BIPM.RI(II)-K4) of national standards of short lived gamma emitting radionuclides (SIRTI), using the high precision, high	• Travel limitations because of the pandemic.

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Project	Deliverables	Work performed in the period (1 January 2021 – 31 December 2021)
year, six radionuclides per site visit	stability SIRTI scintillation counter (reproducibility better than 0.05 %). The SIRTI will be developed, so it can be operated remotely by NMI staff under the supervision of the BIPM staff.	• Successful measurements for the first SIRTI remote comparison at the PTB for ^{18}F, ^{64}Cu and ^{99m}Tc, together with remote measurements of ^{153}Sm and ^{123}I for linking of the SIRTI to the SIR. • Discussions on the development, by the RMOs (APMP and SIM at least), of RMO SIRTI systems. This project will be further studied in 2022.
R1.3:	Technical support for the SIR and SIRTI comparators (quality control checks and continual improvement including software updates). Development of a mathematical model for a second ionization chamber to enable KCRVs to be duplicated without the need to measure all the radionuclides (collaboration with the NPL).	• Quality control checks continued throughout the period. • Design and tests of transport box for the fragile SIRTI detector. Successful transport and setup of the remote SIRTI at the PTB. • Development of software and procedure for remote SIRTI comparisons. • Mathematical modelling to transfer KCRVs from one ionization chamber to another is being developed to avoid the need to measure samples of every radionuclide covered by the SIR. Three possible methods have been proposed and will be tested in 2022 using a software to be developed.
R1.4:	Quality assurance and continual improvement of the high resolution gamma spectrometer for impurity checks and applications in health physics.	• The spectrometer has been mainly used for the measurement of leak test samples for sealed sources.
R1.5:	Tasks to ensure compliance with regulations, including radiation protection monitoring, safety testing of irradiators (for Dosimetry), arranging disposal of radioactive waste, and associated health and safety requirements.	• Arrangements for the disposal of radioactive waste have continued, including the removal of the Quantulus liquid scintillation counter and its ^{152}Eu reference source no more in use in the department. • Extension of license obtained to hold the SIR ^{226}Ra sources for 2 more years. • Extension of license obtained to hold the ^{60}Co Theratron irradiator until June 2027. Strengthening of protection against malicious acts to ensure compliance with new regulations. • 6 barrels of unsealed radioactive waste were disposed to the French agency ANDRA
7. IR-R2: DEVELOPMENT of the NEXT GENERATION INTERNATIONAL REFERENCE SYSTEM (SIR 2.0) The installation and validation of a new SIR based on state-of-the-art instrumentation for measuring low currents and reducing the dependence on sealed radioactive sources, drawing on the studies completed in the previous programme.		
R2.1:	Installation of a new ionization chamber and current measurement system, data collection and analysis software, using new technology for electrical current measurement and reducing the dependence on sealed radioactive sources as reference points.	• Tests of the Ultra-Stable Low-Noise Current Amplifier (on loan from the PTB) have been suspended because of the pandemic as the planned secondee could not come at the BIPM.

IV	Ionizing Radiation Metrology	
Project	Deliverables	Work performed in the period (1 January 2021 – 31 December 2021)
R2.2:	Validation of the new system including determining the long-term stability and precision of the system and confirmation of the linearity of the response (current versus activity).	• ^{166m}Ho sources to replace the SIR ^{226}Ra reference sources have been purchased and should be available for initial tests by middle 2022.
R2.3:	Bilateral comparisons of national standards of gamma-emitting radionuclides (in parallel with measurements on the SIR under BIPM.RI(II)-K1, to establish new key comparison reference values in terms of current versus activity).	• Delayed to next Work Programme.
8. IR-R3: INTERNATIONAL COMPARISON SYSTEMS for ALPHA- and BETA-EMITTING RADIONUCLIDES (ESIR) Provision and extension of the on-demand capability for bilateral comparisons of alpha- and beta-emitting radionuclides for applications in nuclear medicine, environmental protection, radiation protection and nuclear forensics, based on the ESIR established in the previous programme.		
R3.1: *MI Part.: 25*	Bilateral comparisons (BIPM.RI(II)-K5) of national standards of long lived pure alpha- and beta-emitting radionuclides, using the new ESIR comparator established in the previous programme with a reproducibility of better than 0.1%.	• The ^{60}Co pilot comparison exercise continued in 2021. Most of the 11 participants provided their results and almost all the measurements were performed with the ESIR at BIPM. This pilot study is expected to be completed in 2022.
R3.2:	Technical support and continual improvement of the new ESIR comparator including the development of additional software and hardware (such as extending the capability to cover additional radionuclides and the use of digital pulse processing systems).	• A second paper on the ESIR has been published in *Metrologia* • The quality system associated with the ESIR is currently being implemented: – new procedures written, – automation of the calculation, measurement processes and report preparation.
9. IR-R4: AUTOMATION of the PRODUCTION of COMPARISON REPORTS FOR the SIR Development of a machine-readable database of historical SIR data to enable rapid production of comparison reports for the SIR.		
R4.1:	Development of a database of historical SIR data.	• SIR data have been improved to follow FAIR principles • Thanks to the meta-analysis of the database, a survey of primary standards relevant to medical applications was undertaken. A joint paper with NPL, IAEA and NIST is in preparation
R4.2:	Development and validation of report writing software.	• Software commissioning with feedback from NMIs • Integration of the software within BIPM Quality Management system • 10 reports published since January 2021

V	International Liaison	
Project	Deliverables	Work performed in the period (1 January 2021 – 31 December 2021)
1. ILC-L1: LIAISON with MEMBER STATES, ASSOCIATES, the CIPM and RMOs		
ILC-L1:	1) Support to Member States and Associates, CIPM and the BIPM Director; 2) Promotion of the *Metre Convention* and support to potential Member States and Associates; 3) Support for and representation to RMOs (AFRIMETS, APMP, COOMET, EURAMET, SIM and GULFMET).	• As of January 2021, there are 63 Member States, and 39 Associates of the CGPM: – Estonia became a Member State on 19 January 2021having previously been an Associate of the CGPM since 2005, encouraged to accede to the Metre Convention. – Cambodia became an Associate of the CGPM on 1 January 2021. – Zimbabwe excluded as an Associate of the CGPM on 1 January 2021. – Support/advice to the governments of Member States and Associates with outstanding contributions and subscriptions. • Detailed support/advice to governments as they progress towards accession. • Support to the CIPM strategy exercise. Most notably related to the following the CIPM strategy strands: – responding to the evolving needs for metrology – strategy for deepening engagement with other international organizations on measurement science issues – reviewing the strategy for future membership of the organization. • Support to the CIPM in development of its Rules of Procedure (published in April 2021). • Supporting the implementation of the CIPM decision (CIPM/108-34) related to accumulated arrears. Support for the adoption of the CIPM Decisions CIPM/110-06 and CIPM/110-07 in June 2021. Follow up actions with states that have previously been notified of accumulated arrears exceeding the six-year period. • Support to complete the decision CIPM/110-13 to admit GULFMET the full membership to the JCRB, with a voice and voting rights in July 2021. • Supported the CIPM President's initiative by compiling and publishing NMI examples of how their work is supporting the fight against the COVID-19 pandemic. A dedicated repository is available through: https://www.bipm.org/en/metrology-in-the-fight-against-covid-19
2. ILC-L2: LIAISON WITH STRATEGIC PARTNERS		
ILC-L2:	Institutional liaison with International/intergovernmental/Quality Infrastructure: – OIML, UNIDO, ILAC, ISO, OECD, WTO, World Bank;	• BIPM-OIML cooperation: – BIPM-OIML joint publication: National Metrology Systems - Developing the institutional and legislative framework (February 2021) – World Metrology Day activities (see project #ILC-CP5).

V	**International Liaison**	
Project	Deliverables	Work performed in the period (1 January 2021 – 31 December 2021)
	– Institutional liaison with other international organizations as required (BIPM liaises with around 30 international organizations).	• BIPM-WTO cooperation: – Submission of the BIPM statement and representation of the BIPM at the WTO TBTC meetings in February, June and November 2021. BIPM provided expert advice for two initiatives related to the development of the Quality infrastructure indexes (WTO/PTB and UNIDO initiatives). Expected to be published in 2022. • BIPM-OECD cooperation: – Director of the BIPM, together with heads of other IOs, participated as a panelist in the OECD High-Level virtual tour de table: *"Rethinking and modernizing international rulemaking to design better policies for the 21st century"* held as part of the 8th Annual IO Meeting held on 13 September 2021 within the context of the IO Partnership. – Following the High-Level event, breakout sessions on technical expert level were held on 14 September 2021 and the BIPM was a moderator of the Breakout session 1: Enhancing the inclusiveness of international rulemaking to discuss follow-up work of the IO Compendium in regard to stakeholder engagement and co-ordination across IOs. – Compendium of International Organisations' Practices: Working Towards More Effective International Instruments, the first common tool developed collaboratively by some 50 IOs to improve the quality was launched during the 8th Annual IO Meeting. The BIPM is represented in WG2 (implementation), WG4 (evaluation) and WG5 (IO coordination – as a focal point). • BIPM-UNESCO cooperation: – Follow up discussion with the UNESCO Secretariat on the BIPM-OIML joint WMD proposal (WMD to be proclaimed by UNESCO as World Day) (June 2021; outcome is expected at the beginning of 2022) • Bilateral and multilateral agreements with liaisons: – Signing of the BIPM-CTBTO Practical Arrangement (June 2021) – Signing of the BIPM-CODATA MoU (October 2021)
PMD-L1	1) Representation of the BIPM in the CODATA Task Group on Fundamental Constants (4 meetings) 2) Representation of the BIPM in the Executive Committee of the CPEM (Conference on Precision Electromagnetic Measurements) (4 meetings)	• Finalization of the MoU between the BIPM and CODATA, to be signed in early October 2021 • Meeting of the CODATA TGFC on 14-15 September 2021 • Update of the CODATA TGFC website

V	International Liaison	
Project	Deliverables	Work performed in the period (1 January 2021 – 31 December 2021)
TIME-L1 Coordination and promotion of time activities for the advancement in the development of time scales and their applications.	1) Dissemination of TAI/UTC/TT(BIPM) 2) GNSS time transfer 3) GNSS coordination 4) GNSS system time definition and realisation 5) GNSS dissemination of UTC 6) Need in Time and frequency transfer methods.	• Participation to the ITU WP7A meeting in April and September 2021 on the development of a report on the "advantages and disadvantages of the current UTC and possible continuous UTC. • Contribution to the ITU-T SG15Q13 liaisons statement on continuous UTC. • Participation to the International Committee on GNSS (ICG) of United Nation discussing the mutual benefit of UTC and GNSS. G.Petit chairs the subgroup on timing references of WG D • Collaboration to the study of GNSS interoperability using UTC as intermediate pîvot time scale: I. Sesia, G.Signorile, T. Thanh Thai, P. Defraigne, P.Tavella, "GNSS-to-GNSS Time Offsets: Study on the broadcast of a common reference time", GPS Solutions (2021) 25:61, https://doi.org/10.1007/s10291-020-01082-y • Invited presentation to the China Satellite Navigation Conference 2021 in May (online)
TIME-L2 Coordination and promotion of time activities for scientific applications.	TF metrological support to: 1) Space-time references, IERS Conventions 2) Timescales for astronomy/TT(BIPM)/Pulsar timescales 3) Geodetic and geophysical applications of TF metrology e.g. geodetic references, Earth gravity potential.	• Participation to URSI GASS 2021 and presentations of two papers, support to the URSI resolution on Continuous UTC. • Presentation of the paper: J. Levine, P.Tavella, "Discontinuities in Coordinated Universal Time: advantages and perspectives", proceeding of the URSI GASS 2021, Rome, Italy • activities of the new IAG Working Group Q.3 "Relativistic geodesy with clocks", chaired by GP. See publication Van Camp M., Pereira dos Santos F., Murböck M., Petit G., Müller J., Lasers and Ultracold Atoms for a Changing Earth, to be published in Eos (AGU online publication) • G.Petit member of the IGS Directing Board (two meetings). • Participation to Working groups of the IGS (on clock products and on PPP-Ambiguity Resolution) and of the IAU (on Time metrology standards)
Chem-L1	1) Liaison activities with: IUPAC; ISO TC 212, IFCC, WMO, WHO, WADA, Codex, ISO TC 146.	• Agreement to co-host 2022 Metrology for Climate Action Workshop with WMO achieved; • BIPM-WMO 2022 Workshop webpage established, following 5 video conference meetings with core steering group; • Active liaison with ISO TC 146 maintained, including presentation of the CCQM GAWG Task Groups request to revise ISO 13964 and ISO 10313 standards for most accurate values of ozone absorption cross sections recommended by the CCQM; • Active liaison with ISO TC 212 maintained, with revision of ISO Standards 15193 and 15194 underway, and the basis of the JCTLM review process for reference methods an materials

V	International Liaison	
Project	Deliverables	Work performed in the period (1 January 2021 – 31 December 2021)
	2) Liaisons activities related to revision of Ozone standard reference method and global implementation.	• New CCQM-GAWG task on "Ozone cross-section change management" created to coordinate the change process over a 3 to 5 year period. Executive Secretary role held by BIPM staff J. Viallon. • Members of the task group recruited via a published "call for participation" within NMIs and stakeholders; 5 videoconferences held with them to organize future work, structure the group in in 6 task orientated teams and recruit further team members. *Communication team* leadership held by BIPM staff E. Flores. • On-line information related to the task group activities updated on BIPM website • Active liaison with ISO TC 146/SC 3 maintained and proposed change of the ozone absorption cross-section value in the relevant written standards submitted
IR-L1	1) International Commission on Radiation Units (ICRU) (Commissioner and sponsor of Report Committees) 2) International Atomic Energy Agency (IAEA) (SSDL Scientific Committee) 3) International Committee for Radionuclide Metrology (ICRM) 4) ISO (SC2 and working group meetings)	• Participated in 2 virtual meetings of the ICRU Commission and in the final draft of the upcoming ICRU Report on Dosimetry-Guided Radiopharmaceutical Therapy. • Participated (via Zoom) in several meetings of the expert group revising the IAEA Code of Practice TRS-398. • Participation to the IAEA Consultancy Meeting on the Use of the DOL Linac at the IAEA. • Participatation (via Webex) to the ICRM General meeting during which Dr C. Michotte has been elected Vice-President of the ICRM. • Participation to virtual ISO-SC2 meetings, involvement in a joint IEC/SC62C, IEC/TC45 and ISO/TC85/SC-2 group to develop a new standard for the calibration of radioelements by ionisation chambers covering medical and non-medical applications.

VI	Coordination	
Project	Deliverables	Work performed in the period (1 January 2021 – 31 December 2021)
1. CIPM MRA		
ILC-C1:	1) Coordination of the CIPM MRA mechanisms through the JCRB 2) Provision of the KCDB database (Including Exec Sec of the JCRB). 3) Advising the CIPM MRA participants and mining the data for stakeholders	As of December 2020, the CIPM MRA has been signed by representatives of 102 institutes – from 62 Member States, 40 Associates States of the CGPM, and four international organizations – and covers a further 152 institutes designated by the signatory bodies. • During the reporting period around 3041 CMCs were processed through the revised database – KCDB 2.0. • There were 41 new key and 26 new supplementary comparisons registered in the KCDB in 2021 so far. • Support to complete the decision CIPM/110-13 to admit GULFMET the full membership to the JCRB, with a voice and voting rights in July 2021. • The revised CIPM MRA policy and guidance documents, CIPM MRA-P 11 to P13, and CIPM MRA-G 11 to G13 have been completed, approved and uploaded to the BIPM website. • Organized the 43rd in March 2021 and the 44th meeting of the JCRB in September 2021 as online conferences. Participants were representing all six RMOs and the CIPM. • Publication and presentation of KCDB reports to the JCRB in March and September 2021; KCDB reports have been made publicly available through the JCRB website. • An evaluation of the system's performance has been conducted and included in the two KCDB reports to the JCRB. • The KCDB 2.0 platform was fully adopted by the CCQM for CMC submissions in 2021. • Support to RMOs for their new appointed TC Chairs to enter and registered with appropriate user rights in the KCDB. • Registration of DIs as participants of the CIPM MRA: One DI has been withdrawn as a participant of the CIPM MRA by the national authority, one has joined as a new DI, and another one has changed and amended its scope of designation. • Support to the KCDB office on greyed-out CMCs, their status, and their handling in the KCDB and the RMOs.
2. JCGM		
ILC-C2:	Provision of JCGM Executive Secretary and rapporteur for WG2 (JCGM- one annual meeting, JCGM WG2 - two annual meetings), general support to JCGM, representation in JCGM WG2.	• Full support to the JCGM meeting held online on 6 December 2021, including publication of the meeting minutes • Full support to the JCGM-WG2 meetings held online on 31 May, 10 September and 7-10 December 2021 including publication of the meeting minutes.

VI	Coordination	
Project	Deliverables	Work performed in the period (1 January 2021 – 31 December 2021)
		• First CD of JCGM 200: International Vocabulary of Metrology, 4th edition was sent to NMI Directors and JCGM MOs for consultation in January 2021. • Assisted with collation and participated in discussions on the 1700+ responses received following the end of the VIM4 CD consultation exercise in July 2021. • Full support to JCGM-WG2 during development of the VIM4 CD. • Participated in the JCGM-WG2 Webinar: "An overview - New edition of the International Vocabulary of Metrology (VIM4)", which was hosted by the BIPM on 6 May 2021. • JCGM-WG2 SharePoint site inaugurated.
IR-C1:	Provision of the Scientific Secretary for JCGM WG1 and support including: *1) Rapporteur* 2) Two annual meetings.	• Summary report of December 2020 meeting produced. • Special JCGM-WG1 meetings on GUM-related definitions and on New Measures of Uncertainty, organized by teleconference in January and September 2021. • May meeting of JCGM-WG1 organized by teleconference. • Review and update of the JCGM-WG1 web pages and working documents on the new BIPM web site.
3. JCTLM		
Chem-C3 Provision of JCTLM Executive Secretary in order to support:	Support for: 1) JCTLM Executive and WGs (eight meetings) 2) JCTLM Database entry/nomination review process 3) Maintenance of: JCTLM Database 4) Development of new platform and architecture for the JCTLM database, including machine readability, and replacing obsolete software	• Report of the 22nd Executive Committee meeting drafted and published. • Report of the December 2020 DBWG meeting drafted and distributed. • Videoconference of JCTLM Executive held in March and July 2021. • The 8th Issue of the JCTLM Database Newsletter and a Special Report on ISO 17511:2020 edited and published; • Call for experts participation among the CCQM WGs for extension of JCTLM Quality System Review Team Membership; • Preliminary review of 183 nominations before distribution to the DBWG review teams completed; • 33 new entries published in the JCTLM database • Completion of the technical specifications and call for tender for new JCTLM Database structure and platform • Organization completed for online JCTLM Members and Stakeholders Meeting and Workshop on Overcoming challenges to global standardization of clinical laboratory testing: reference materials and regulation to be held 6-10 December 2021

VI	Coordination	
Project	Deliverables	Work performed in the period (1 January 2021 – 31 December 2021)
4. NMI DIRECTORS and RMO CHAIRS MEETING		
ILC-C3:	1) To work with the panel of NMI Directors to organize an annual meeting at the BIPM 2) Organization of the CC Presidents meetings 3) Access to and understanding of best practice in the operation of RMOs *a) Development of a global perspective on key issues;* *b) Optimal support for states with emerging metrology systems* *c) Facilitated by the BIPM convening annual meetings of the RMO Chairs*	*1.* No CC Presidents' meeting requested for 2021. *2.* Support for emerging states addressed via the CBKT programme.
5. Support of CCs (including provision of Executive Secretaries)		
PMD-C1 Provision of CCEM (Electricity and Magnetism) Executive Secretary in order to support:	Provision of CCEM (Electricity and Magnetism) Executive Secretary in order to support: 1) Two CCEM meetings 2) Annual working group meetings 3) Pro-active interaction on strategy and communication 4) Coordination of CCEM processes 5) Related liaison with RMO technical committees (4 meetings)	• Organization of the 32nd CCEM meeting and of CCEM WG meetings in April 2021 • Finalization of the new CCEM strategy document • Participation in the review of comparison reports • Participation in the APMP TC-EM meeting • Participation in GULFMET TC-EM meeting
PMD-C2 Provision of CCM (Mass and Related Quantities) Executive Secretary in order to support:	Provision of CCM (Mass and Related Quantities) Executive Secretary in order to support: 1) Two CCM meetings 2) Annual working group meetings 3) Pro-active interaction on strategy and communication 4) Coordination of CCM processes 5) Related liaison with RMO technical committees (4 meetings)	• Organization of the 18th CCM meeting in May 2021 and of the CCM WG meetings in April, May and September 2021 • CCM Working Group on Strategy: preparation of the WG meeting; establishment and following-up of the CCM action plan 2021-2022 • CCM Strategy 2022-2032: drafting the Strategy document; organization of the Task Group meetings and work • Updating the CCM web page on the new BIPM website; 1 CCM Newsletter • Coordinating of the registration, approval and publication of the final reports of a large number of comparisons.

VI	Coordination	
Project	Deliverables	Work performed in the period (1 January 2021 – 31 December 2021)
		• Closing speech "The new definition of the kilogram and the current status of mass traceability" at virtual SIM "MWG 7-MASS AND RELATED QUANTITIES" workshop • Steering and Program Committee of the International Conference of Weighing 2023 • Participation in the EURAMET TC-M meeting • CCM report to the CCU meeting in September 2021
PMD-C3 Provision of CCU (Units) Executive Secretary in order to support:	Provision of CCU (Units) Executive Secretary in order to support: 1) Two CCU meetings 2) Pro-active interaction on strategy and communication 3) Coordination of CCU processes	• Organization of the CCU meeting in September 2021 • Organization of a remote meetings of WG-S in January 2021 and of WG-CMT in June 2021 • Consultation of CCU members about their opinions on units for angles and on definitions for core metrological terms • Organization of a survey amongst NMIs and liaison organizations of the CCU about implementation of the revised SI • Responding to questions received by the webmaster about SI and other units.
Time-C1 Provision of CCTF (Time and Frequency) Executive Secretary in order to support:	1) Organizing the CCTF bi/triennial meetings 2) Providing secretariat of CCTF and WGs 3) Pro-active interaction on strategy and communication 4) Coordinate CC processes including comparison and other MRA reports. 5) Key comparisons in time and frequency 6) Recommendation of standard frequencies as secondary representations of the second	• Proactive support to the CCTF 22nd meeting with a first session in October 2020 (online) and a second session in March 2021 (online). The first online session focused on CCTF 'hot topics" with invited presentations stimulating the discussion. Then an online survey was launched to NMIs, Liaisons, and stakeholders with the critical analysis of more than 200 answers. Decision on future actions leading to 6 CCTF recommendations in March 2021 and to 2 proposed resolutions to the CGPM 2022. Hot topics include: 1. Update roadmap towards a new definition of the second 2. Need of a continuous UTC timescale 3. Promoting the mutual benefit of UTC and GNSS 4. CB activities and sharing resources to improve international timekeeping • Support to the CCTF WG meetings and to the Task Force on the "updating the roadmap to the redefinition of the second", and the Task Group on the "Traceability from GNSS measures" within the CTF WG on GNSS. • Online meetings of the o WG GNSS o WG TAI o WG TWSTFT o WG strategic Planning (5 meetings) o Joint WG CCL CCTF FS

VI	Coordination	
Project	Deliverables	Work performed in the period (1 January 2021 – 31 December 2021)
		• Participation to the SIM TCTF meeting (online), May 2021
Time-C2 Provision of CCL (Length) Executive Secretary in order to support:	1) CCL meetings 2) Participation in WGs 3) Pro-active interaction on strategy and communication 4) Coordination between NMIs for length related activities. Key comparisons in length, support to comparisons of stabilized lasers piloted by NMIs 5) Recommendation of standard frequencies for the practical realization of the metre	• Analysis of the need of Digitalization activities in support to the realization of the meter. Survey to the NMIs and analysis of feedback. • Meetings of all WGs • Preparation of CCL meeting in October 2021 • Publication of *Metrologia* Focus Issue on Length, 2021 • CMC transformation to quantity equation, work in progress
Time-C3 Provision of CCAUV (Acoustics, ultrasound and vibration) Executive Secretary in order to support:	1) Biennial CCAUV meetings and three WG meetings 2) Pro-active interaction on strategy and communication 3) Development of strategic plans 4) Coordinate review of CC and RMO comparison reports before publication 5) Related liaisons with RMOs.	• Meeting of all WGs • Preparation of CCAUV meeting in November 2021
Chem-C1 Provision of CCQM (Amount of Substance) Executive Secretary in order to support:	1) CCQM meetings (four plenary meetings) and eleven WG meetings (44 meetings in total) 2) Pro-active interaction on strategy and communication 3) Coordination of review of CC and RMO comparison reports before publication 4) Development and review of CCQM documents and guidelines 5) Organization and coordination of CCQM workshops	• On-line CCQM Plenary meeting organized and run over 3 successive days in April 2021, with report of meeting published in July 2021 • 31 videoconference sessions organized by the BIPM for 11 CCQM WGs to replace April 2021 face-to -face meetings. • Coordination of group organizing CCQM Covid-19 workshops, with 1 CCQM Webinar on Ensuring the reliability of measurements in response to the Covid-19 pandemic, run in March 2021, and support for the CCQM on-line workshop on Metrology for Infectious Diseases and Pandemic preparedness • Support for CCQM SPWG and CCQM in drafting and publication of CCQM Strategy for 2021-2030 • Support for CCQM WGs with publication of 9 technical WG strategy documents
Chem-C2 Provision of CCPR (Photometry and Radiometry) Executive	1) Two CCPR plenary meetings and associated WG meetings 2) Pro-active interaction on strategy and communication	• Started revision of Strategy document and adoption of new format; 3 videoconferences with the Task Group in charge of the Strategy • CCPR-WG-CMC virtual meeting (part 1) hosted in Sep. 2021

VI	**Coordination**	
Project	Deliverables	Work performed in the period (1 January 2021 – 31 December 2021)
Secretary in order to support:	3) Coordination of review of CC and RMO comparison reports before publication 4) Development and review of CCPR documents and guidelines	• Support provided for the publication of CCPR-G9 "rules for review of CMC claims and requirements for supporting evidence" • Support provided for the publication of 4 new CCPR RMO comparisons reports in the KCDB
IR-C2:	Provision of CCRI (Ionizing Radiation) Executive Secretary in order to support: 1) Biennial CCRI and sections I, II and III meetings 2) Regular meetings of seven working groups 3) Development of strategic plans 4) Co-ordination engagement with RMOs	• Validation and publication of the updated version (2.0) of the CCRI strategy. • CCRI webinar series: 7 organized webinars: *14/01-Radiation processing, 18/02-Ionizing Radiation Metrology at CERN*, *18/03-ISO4037 What is new and why?*, *20/05-Metrology for Radionuclide Therapy*, *23/06-The current status of brachytherapy dosimetry, 12/10-ICRU report 95, 17/11-Dosimetry of cosmic radiation* • Setting up of the CCRI communication Working Group (first meeting 28/02/2022) • One meeting was held in May of the joint CCEM-CCRI Task Group on low electrical current measurement. • Three meetings were held in February, May and October of the CCRI Radionuclide Therapy and Quantitative Imaging Working Group (CCRI-RTWG) • Meetings were held in March, April and May of the CCRI RMO Working Group on IR CMCs (CCRI-RMOWG). • Meetings were held in March and May of the CCRI Section II: Key Comparisons Working Group (CCRI-KCWG(II)) • Meetings of 28th CCRI and of the 3 related sections held in June. • Co-pilot of the ^{109}Cd CCRI Section II comparison exercise • Co-pilot of the thermal neutron CCRI(III).K8.2024 comparison
IR-C3	Provision of CCT (Thermometry) Executive Secretary in order to support: 1) Biennial CCT meetings and twelve WG meetings 2) Pro-active interaction on strategy and communication 3) Coordinate review of CC and RMO comparison reports before publication 4) Related liaisons with RMOs	• The 29th meeting of the CCT was held as 5 separate online sessions that started in October 2020 and ended in February 2021. A number of WG and TG meetings were also organized. • Minutes of each CCT session were drafted, where the CCT report to the CIPM is a summary of these. • One new member and two new observers were elected. • The update of the Strategic Planning was triggered and has been completed. • Two new TGs were created, on Body Temperature Measurements and Air Temperature, both with concrete objectives. • Liaison with WMO is maintained by participation of CCT members and experts in the WMO expert groups. The CCT, and the CIPM, is also represented at the Global Climate Observing System Surface Reference Network Task Team (TT-GSRN).

VII	Capacity Building and Knowledge Transfer	
Project	Deliverables	Work performed in the period (1 January 2021 – 31 December 2021)
1. PLANNING and COORDINATION of BIPM CBKT PROGRAMME ACTIVITIES		
ILC-CBKT1	1) Planning, coordination and operation of core CBKT activities supporting the CIPM MRA and sponsor supported topic based CBKT activities, including scheduling, course design, call and selection processes (liaising with RMOs on prioritization of candidates), identification of speakers, funding of participants' costs where appropriate, provision of BIPM lecturers and sourcing of external RMO/NMI lectures together with all associated logistics. 2) Developing and managing of the BIPM RMO framework ensuring coordinated delivery of CBKT activities by BIPM and the RMOs – Liaison with RMOs to ensure coordinated CBKT delivery. 3) Development of remote learning capabilities: – online short courses. – online technical exchanges. – E-learning capabilities for CBKT.	• Emergence of COVID-19 crisis required complete re-evaluation of the delivery mechanisms of the CBKT programme, effectively requiring full redesign. • The "remote-learning" capabilities were which launched in 2020 were extended with the development of an e-learning platform. The platform was launched in April 2021 and is populated with four courses so far. They are related to the technical areas of the BIPM, as well as on the mechanisms of the CIPM MRA. • Discussions opened regarding the possibility of hosting the RMO's e-learning material on the BIPM's e-learning platform. Hosting the RMO e-learning material would enable cross-RMO access to material (reducing the need to develop duplicate material) and facilitates joint development of material. • Secured funding from METAS for the CBKT project planned in 2021. METAS is providing the financial support for the CBKT activates within 2020-2021.
2. DELIVERY OF, and LECTURING on CORE BIPM CBKT ACTIVITIES		
ILC-CBKT2	1) Delivery of, and lecturing on (including using the remote learning tools), core CBKT activities supporting the CIPM MRA: – Future leaders (aimed at new and potential RMO TC/WG Chairs) – Sound beginning (aimed at new participants in the CIPM MRA) – Orientation for new RMO TC/WG Chairs – Participation in the activities of the Metre Convention (including orientation for 'newcomers').	• BIPM-ILAC Joint initiative webinar "Mining KCDB 2.0 in the context of accreditation" was organized with participation of more than 600 experts from accreditation community. • CIPM MRA webinar dedicated for CARICOM member NMIs/DIs was organized. • CIPM MRA webinar dedicated for GULFMET member NMIs/DIs was organized. • Four online projects on core CBKT topics have been organized involving 535 participants: – Technical exchanges for CMC writers in General Physics – Technical exchanges for CMC writers in Ionizing Radiation – Technical exchanges / online session on comparisons was organized. – Technical exchanges for TC/WG Chairs operating the system.

VII	Capacity Building and Knowledge Transfer	
Project	Deliverables	Work performed in the period (1 January 2021 – 31 December 2021)
		Cumulative overview of the CBKT: • 39 CBKT initiatives were organized: 24 projects at the BIPM and regions. 15 (+7 repeated) projects online. • Overall, 1728 participants from 102 countries participated in various CBKT initiatives: 505 participants at the BIPM and regions physically; 1223 participants in online sessions. Plus 380 registered participants in e-learning. • Beneficiaries of the CBKT initiatives by RMOs: – 225 - AFRIMETS – 378 - APMP – 321 - COOMET – 393 - EURAMET – 184 - GULFMET – 227 - SIM
3. VARENNA METROLOGY SCHOOL		
ILC-CBKT3	Delivery of joint Varenna metrology school for world class young scientists/metrologists - with the Italian Physical Society.	• The project is planned in 2023, however there is now some uncertainty on the timing.
4. Laboratory support for capacity building and knowledge transfer activities		
ILC-CBKT	1. Delivery of, and lecturing on, sponsor supported topic based CBKT activities on courses (topics of interest chosen with the NMI/DI community and sponsors): – at the BIPM and – within the RMO Framework (i.e. at courses arranged in the regions by the RMOs), and aligned with NMI laboratory placements	• Due to COVID-19 crisis: – 2020 BIPM-SIM Training course: KCDB 2.0. Rescheduled for 2022. – 2020 BIPM-APMP Training course: Timescale and Algorithms. Postponed.
PMD-CBKT	Planning, coordination and delivery of the capacity building and knowledge transfer activities in the field of electricity and mass metrology.	• The CCEM is planning a series of webinars on electrical metrology.
TIME-CBKT	Planning, coordination and delivery of the capacity building and knowledge transfer activities in the field of time and frequency metrology.	• Collaboration with the CCTF and the CCTF WG on TAI and Algorithms to plan a CBKT program based on shared resources in collaboration with NMIs.

VII	Capacity Building and Knowledge Transfer	
Project	Deliverables	Work performed in the period (1 January 2021 – 31 December 2021)
		• Presentation of a paper on the CCTF/BIPM CBKT project: P.Tavella, Y. Hanado, "BIPM Capacity Building and Knowledge Transfer program on Time Scale Realization", proceeding of the URSI GASS 2021, Rome, Italy • Contributions to the book of the Italian Physical Society: – P. Tavella, "Timekeeping and navigation systems", in Proceedings of the International School of Physics "Enrico Fermi", Course 206: "New Frontiers for Metrology: From Biology and Chemistry to Quantum and Data Science", edited by M.J.T. Milton, D. Wiersma, C. Williams and M. Sega (IOS Press, Amsterdam; SIF, Bologna) 2021. – P. Tavella, "Analysing and obtaining statistical information on time varying quantities", in Proceedings of the International School of Physics "Enrico Fermi", Course 206: "New Frontiers for Metrology: From Biology and Chemistry to Quantum and Data Science", edited by M.J.T. Milton, D. Wiersma, C. Williams and M. Sega (IOS Press, Amsterdam; SIF, Bologna) 2021.
Chem-CBKT1 Metrology for Safe Food and Feed	1. Development and publication of purity evaluation and calibrant assessment guidelines for 4 mycotoxin standards 2. On-line laboratory training for NMI scientists in pure material and calibrant characterization methods 3. Coordination of 3 mycotoxin calibration solution key comparisons to support new NMI capabilities 4. Published Reference methods and data, with supporting reference materials from Collaborating NMI(s), for veterinary drug materials, supporting CBKT program on Metrology for Safe Food and Feed 5. Published Reference methods and data, with supporting reference materials from Collaborating NMI(s), for Pesticide materials, supporting CBKT program on Metrology for Safe Food and Feed.	• CCQM-K154.b (AfB1 mycotoxin calibrant) measurements completed and evaluated. Comparison measurement results presented and individually discussed in video-conference with KCRVs agreed by OAWG supporting the 12 NMI participations. Draft B report 60% complete. • Call and protocol for key comparison CCQM-K154.c (DON mycotoxin calibrant) written, accepted by OAWG and distributed to OAWG. DON stock solutions shipped to CBKT participants. Registration launched and finalized with the 10 NMI participations. Data submission form and shipping information provided to participants. • PAT stock solutions shipped to potential CBKT participants for key comparison CCQM-K154.d (PAT mycotoxin calibrant) • Ochratoxin A material scale-up and clean-up completed at NRC. Shipping of study material to the BIPM arranged with NRC. • Protocol for Knowledge Transfer Study on the purity evaluation of Tetracycline developed with participation of 14 NMI/DIs confirmed. • A 6 month on-line training course on Impurity Content Quantification in Organic Pure Materials was launched on the e-learning platform of the BIPM in May. Participants from 9 NMIs enrolled in the full online course, consisting of six modules, with activities on 4 modules completed. In addition, over 100 NMI scientists from 22 countries have accessed the recorded lectures and learning material available through the BIPM e-learning portal.
Chem-CBKT2&3 Metrology for Clean Air	1. On-line training course on the use of FTIR for gas standards and metrology (6 month visiting	• The On-line training course on the use of FTIR for gas standards and metrology launched on the e-learning platform of the BIPM on September 1st, with scientists from NMISA and

VII	Capacity Building and Knowledge Transfer	
Project	Deliverables	Work performed in the period (1 January 2021 – 31 December 2021)
	scientist secondments planned for 2020 and 2021) 2. Development of on-line training course on dynamic methods for gas standards, including magnetic suspension balance and METAS REGAS system	NIMT following the course for 6 months. 80 percent of the course content has been put on-line, consisting of fourteen videos contained in four modules. • Initial characterization of METAS REGAS system by FTIR and comparison to the BIPM magnetic suspension balance completed. Virtual meetings held with METAS staff to define the content of the on-line training course.
Chem-CBKT4 Metrology for Accurate Patient Care	1. Development of E-training material on peptide pure material standard characterization and value assignment	• Activity to start in 2022
IR-CBKT:	Planning, coordination and delivery of the capacity building and knowledge transfer activities in ionizing radiation.	• BIPM e-learning course on "*How to enter a CMC claim for ionizing radiation metrology*" including introduction by NMISA, on the Moodle platform • Participation to the preparation of the workshop on "The international System of Units (SI) in FAIR digital data" • Training in high-energy x-ray beam calibrations (LINAC) at DOSEO for the IAEA. • Virtual audit of the radiation protection services for the SSDL of Colombia. Preparation of the report for the national accreditation body (ONAC).

VIII	Communication and Promotion	
Project	Deliverables	Work performed in the period (1 January 2021 – 31 December 2021)
1. PROVISION of BIPM INTERNET		
ILC-CP1:	1. Provision of BIPM internet. 2. Website update - to adapt effectively to the rapidly changing world of electronic media to ensure that the website continues to deliver services effectively and portrays an up-to-date image of the BIPM.	• The BIPM's new website, based on an updated Content Management System and with a new graphic design, was released to the public in April 2021, following internal publication (on-site) in 2020. • During a typical working week, the BIPM website receives visits from approximately 2000 different users per day. • The new website is fully responsive, making it more comfortable than before for users browsing the site on a small screen. Approximately 25% of visitors now access the site from a mobile phone. • As before, all unidentified users (without a login) have access to all open-access content. • Restricted-access content (which was previously hosted on a separate system) is now integrated within the Content Management System and its delivery is tailored to the profile of each individual user. This makes the website both more secure and easier to use, as an individual belonging to several different working groups now only needs one (individual) login. • Access rights are managed through the BIPM's centralized Meetings Office database, which also provides data relating to meetings, CC and WG members, contacts, Member States and Associates, participants in the CIPM MRA, and BIPM staff. • The dedicated search engine covers both open and restricted-access content (with the results tailored to the access rights of the individual user), as well as the contents of the KCDB, the JCTLM, and *Metrologia*. • The website currently contains 910 official documents and more than 24 450 working documents, and has over 10000 individual user accounts (providing access to restricted content where appropriate). • The "webmaster" email address is now shared by four BIPM colleagues, to ensure a rapid response to any queries. • The BIPM web team continues to add content as time permits, and a maintenance contract is in place with an external contractor to allow for the correction of any bugs and the introduction of some new facilities.
2. FORMAL REPORTING & PUBLICATIONS		
ILC-CP2:	Generating BIPM reports including drafting/minuting, editing, translation into French,	• Typeset and published the report of the 109th meeting of the CIPM (October 2020) in English and French.

VIII	Communication and Promotion	
Project	Deliverables	Work performed in the period (1 January 2021 – 31 December 2021)
	typesetting and publication of CIPM and BIPM reports, publications and posters.	• Drafted, edited, typeset and published the report of the 110th meeting of the CIPM (Session I, June 2021 and Session II, October 2021) in English. French translation of Session I. • Published the BIPM Annual Review 2020/2021 following a redesign • Published the Financial Report 2020 in French and English • Typeset the Strategic Plan (2022) for the BIPM • Published version 1.08 of the SI Brochure (editorial changes) • Edited and published the Report of the 24th CCPR meeting (2019) • Edited and published the Report of the 26th CCQM meeting (2021) • Edited and published the Report of the 29th CCT meeting (2020-2021) • Edited and published the Report of the 32nd meeting of the CCEM (2021) • Edited and published the Report of the 28th meeting of the CCRI (2021) • Edited and published the Report of the 25th meeting of the CCU (2021) • Edited and published the Report of the 18th meeting of the CCL (2021) • Published the Time Annual Report 2020 • Published 23 news stories • Published the BIPM eNews • Edited, typeset and published the JCTLM Newsletter 2021 and one Special Report • Published the 'News from the BIPM laboratories 2020' • Updating the BIPM social media presence on LinkedIn and Twitter
3. *Metrologia*		
ILC-CP3:	Editing and publication of *Metrologia* 1. To ensure the success of *Metrologia* as the key scientific publication for high level metrology with an increase in impact factor. 2. To increase the number of annual issues of *Metrologia* from 6 to 10 3. Maintain a viable journal taking account of the trend towards "open access" for journals.	• Sustainable editorial team comprising the Editor and three Deputy Editors: Sten Bergstrand (RISE), Giovanni Mana (INRIM), Rod White (New Zealand) • Open or recently completed Focus issues: Length Metrology, NEWRAD 2020, Measurements of the Newtonian Constant of Gravitation • Published articles: 95 (2020: 113) • Open Access articles: 36 (2020: 28) • Receipt-Online Publication times: 147 days (2020: 188 days) • Impact factor 2020: 3.157 (2019: 3.058)

VIII	Communication and Promotion	
Project	Deliverables	Work performed in the period (1 January 2021 – 31 December 2021)
4. LIBRARY		
ILC-CP4:	Journal subscriptions (on-line or hard copy) buy-per-view scientific articles and books for BIPM staff)	• Renewal of 10 journal subscriptions • Purchase of 8 books and 10 articles
5. WORLD METROLOGY DAY		
ILC-CP5:	To build on the success of World Metrology Day, doubling participation through all media by 2022 (Project run jointly with OIML) with participation by at least 50 states. Provision of: 1. Website content, 2. Poster (in consultation RMOs and with selected NMI), 3. Directors messages, 4. Events listings for all participating countries 5. Press release 6. Participation in at least 4 national events in countries with emerging metrology systems	• The project is run jointly by the BIPM and the OIML. The theme for 2021 was *"Measurement for Health"*. • The 2021 poster was designed in collaboration with the GULFMET RMO and specifically with SASO, Saudi Standards, Metrology and Quality Organization. The poster was translated into more than 30 languages and information on 38 national celebratory events is provided on the 2021 World Metrology Day Resource Website http://www.worldmetrologyday.org/ • Participated in World Metrology Day online events organized by Member States and Associates. • Initial work has been launched for WMD 2022 with OIML and COOMET including revamping to facilitate social media promotion of WMD. The theme for 2022 is "*Metrology in the Digital Era*."
6. IMPACT STUDY		
ILC-CP6:	Authoritative independent study highlighting the impact arising from metrology in the Quality Infrastructure.	• Ongoing discussions with OECD. Webinar on QI is expected to be held on 19 October. Strong support expressed during the 8th Annual IO Meeting held in September 2021 by OECD IO Partnership members to QI topic as one of the thematic areas to be explored in future • Proposal to focus efforts and resources on INetQI "Single library" project is under consideration.
7. WORKSHOPS ON KEY TOPICS		
ILC-CP8:	To identify (with the CIPM and NMIs) topics of importance to the metrology community (such as 'big data') to be addressed at BIPM Workshops.	• The International System of Units (SI) in FAIR digital data organized in February 2021 (online).

IX	Digital Transformation	
Project	Deliverables	Work performed in the period (1 January 2021 – 31 December 2021)
1. DIG-D1: Machine-readable functionality for the KCDB 2.0 and JCTLM The path towards data meeting the FAIR agenda requires, in the first instance, that it should be "Findable and Accessible". Under this activity the first machine-readable functions for the principal data base products of the BIPM (KCDB 2.0 and JCTLM) will be developed and tested.		
D1.1:	Open new (digital) applications for the Key Comparison Data base by developing a "machine-readable" interface for the KCDB (by mid-2021). The interface will be "beta-tested" by experts nominated by the JCRB.	• An Application Programming Interface (API) was realized for search of CMCs in the KCDB, now available online, supported by detailed written guidance.
D1.2:	The revision of the software platform for the JCTLM database in underway. It will include an interface to facilitate machine readability as part of its specification.	• Call for tender process for new JCTLM database completed including inclusion of application programming interface.
2. DIG-D2: Provision of BIPM documents and other text data in xml and other machine-accessible formats The BIPM publishes a number of important reference publications used by the metrology community. The actions proposed here will be the first steps towards providing true digital versions of these publications.		
D2.1:	Preparation of a version of the 9th-edition of the SI brochure in xml and support for JCGM/WG2 as they progress their JSON version of the annotated VIM 3.	• Continuing work on the encoding of the XML version of the SI brochure.
D2.2:	Development of a policy for allocating Digital Object Identifiers (DOIs) and necessary meta-data to publications (e.g. CIPM publications, selected CC documents). This requires the identification of the highest priority documents and the services of a DOI registration agency (e.g. Crossref.com). The policy will also consider the benefits of allocating DOIs to specific strings of text information (eg definitions, CMCs etc).	This deliverable has evolved and broadened such that the focus is now on developing a policy for making the BIPM's documents Findable and Accessible according to the FAIR guidelines, and evaluating the extent to which the BIPM's data might also be made Interoperable. • A first draft policy document has been written, including recommendations on: how to make the BIPM's documents - and necessary document fragments, such as Resolutions and definitions - Findable and Accessible according to the FAIR guidelines; which documents need Digital Object Identifiers; and which DOI Registration Agency might be appropriate. • A semantically encoded version of the SI Brochure (in XML, HTML and PDF) is nearing completion, using UnitsML encoding of the units. • Work towards a machine-readable version of the SI Brochure is advancing. • A study is ongoing as to which services might usefully be made machine-readable – including documents such as the mises en pratique.

IX	Digital Transformation	
Project	Deliverables	Work performed in the period (1 January 2021 – 31 December 2021)
D2.3:	Following the development and implementation of a policy for allocating DOIs to documents and to specific text strings it will be necessary to develop a specification for an open-access document repository (for implementation post 2022)	As a key part of making the BIPM's documents Findable and Accessible, this deliverable has evolved towards developing an API interface for the BIPM's bibliographic data, including machine-readable references such as URNs/URIs. • Planned for 2022: Preparation of the web landing pages for those publications requiring a DOI. • Post-2022: Development of a bibliographic API to facilitate finding and accessing the BIPM's documents and document fragments from machine- as well as human-readable metadata, including Unified Resource Names (URNs) and - for self-standing documents – DOIs.
3. DIG-D3: Support for Digital Transformation activities at the CIPM and the JCGM		
D3.1:	Support for the CIPM Task Group for the Digital SI in the preparation of the Workshop (February 2021) Support for the JCGM in the development of a policy for true digital publications and for WG 1 and 2 as they apply the policy to the GUM and the VIM.	• The International System of Units (SI) in FAIR digital data online Workshop was organized in February 2021 with participation of 734 experts around the world. • JCGM WG2 has developed the document "Strategies for electronic/digital formats in which to provide the VIM4". • JCGM-WG1 discussed the subject of the digital SI and considered that the development of API could be helpful on the long term for sharing information on measurement uncertainty between different communities. • A survey through the CCs on digital transformation needs and demands was initiated, and a questionnaire drafted. The questionnaire was circulated to CCAUV and CCEM members to feedback their views. In 2022 and based on the experience with the returned CCAUV and CCEM questionnaire, the survey shall be amended to all the other CCs.
D3.2:	Development of a strategy for Digital Transformation activities in the 2024-27 WP to achieve data and document services that are "Interoperable and Re-usable" (ie "machine actionable") within the context of the FAIR framework. The strategy will include consideration of the future opportunities for the IMRR.	• The Draft Strategy of the BIPM for 2024-2027 includes strategic directions on digital transformation and new digital services. Following completion of the consultation process for the strategy, the 2024 - 2027 Work Programme will be developed and then subject to consultation.

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